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Vol. XIX, No. 2 *PSYCHOLOGICAL REVIEW PUBLICATIONS* April, 1936

Journal of Experimental Psychology

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PUBLISHED BI-MONTHLY
FOR THE AMERICAN PSYCHOLOGICAL ASSOCIATION
BY THE PSYCHOLOGICAL REVIEW COMPANY
PRINCE AND LEMON STS., LANCASTER, PA.
AND PRINCETON, N. J.

Entered as second-class matter, July 1, 1920, at the post-office at Lancaster, Pa.

PUBLICATIONS

OF THE

AMERICAN PSYCHOLOGICAL ASSOCIATION

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PSYCHOLOGICAL REVIEW COMPANY

PRINCETON, NEW JERSEY

Journal of
Experimental Psychology

VOL. XIX, NO. 2 APRIL, 1936

LEARNING CURVES FOR CONDITIONING AND MAZE LEARNING

BY WALTER S. HUNTER

Clark University

INTRODUCTION

In some recent studies of conditioning, extinction, and maze learning in rats (**3**, **4**), I have secured data which make possible a comparison of the forms of the curves of acquisition for conditioned responses and maze habits. Kleitman and Crisler (**6**), Hilgard (**1**), and Hull (**2**) have published curves for conditioning which in each case show an initial positive acceleration. This, plus Hull's suggestion that such curves, if extended, should be S-shaped, suggests the desirability of a further consideration of the problem. Hilgard's curve is for a single human subject. The curve which Hull presents is a Vincent curve for the salivary reflex in 4 of the dogs used by Kleitman and Crisler. The development of this reflex was measured in terms of the amount of saliva secreted in successive periods; and it is not clear that the resulting data were treated, or could be treated, in a way comparable to the ordinary learning data where a definite criterion of mastery is set.

The usual learning curves for mazes are plotted in terms of time or errors per trial, or per tenth of the learning process. Such curves are for elimination, and they begin high and end low. Acquisition curves, on the other hand, begin low and

end high. In the present study, I have converted error scores on the maze into correct responses, thus making possible a direct comparison with the acquisition scores in the establishment of a conditioned response.

Subjects and Methods

Forty-six white rats between 2 and 3 months of age were used for conditioning. These rats were all blinded prior to the experiment. (Of these 46 animals, 16 had been trained in Experiment 1 and the remainder in Experiment 2 of the work previously reported [3].) Thirty-six blind rats were trained on an elevated maze approximately 2 months after being conditioned to the buzzer. Thirty of these animals belonged to the group of 46 whose records on conditioning are here utilized. To a large extent, therefore, the same rats are used in the two experiments of conditioning and maze learning, thus insuring a high control of the selection factor in so far as that might influence a comparison of the respective learning curves.

The conditioning apparatus has been described elsewhere (3). The response required of the animal is a run of at least a body-length in either direction in a circular runway. The unconditioned stimulus was an electric shock; the conditioned stimulus, a buzzer which sounded at one minute intervals under the control of a synchronous motor timer. *If the rat responded as required within a period less than 2 secs. after the buzzer sounded, it received no shock.* If no adequate response was made in this period, a shock was given 2 secs. after the buzzer sounded. The apparatus was placed in a highly sound-proofed double box through whose window the rat's behavior was observed. The criterion of mastery in all cases for the conditioning was set at 10 successive runs to the buzzer. All training was completed at one sitting. Each presentation of the buzzer is called a trial; and since the buzzers came at 1 min. intervals, the total duration of the training can be determined from the data given below under Results. (Training never exceeded a period of 2 hours in the animals here concerned. Occasionally a rat will show, as startle responses, 10 successive runs to the buzzer prior to receiving any shocks. No such animals are here included.)

The elevated multiple-T maze has been described elsewhere (4). It contained 6 culs-de-sac, and the order of the correct turns was *lrrlrl*. (The maze experiment was conducted in a relatively sound-proof room.) Only forward going errors were recorded, and retracing was almost completely prevented. The rats were first trained 3 trials per day for 10 days on a preliminary runway containing one left turn. After this they were trained on the maze until 3 successiye runs were made without error. Three trials were given on each of the first two days, and 6 trials were given daily thereafter. Under the conditions of the experiment only 6 errors could be made by one rat at one trial, one forward going error at each cul-de-sac. The error records were converted into correct response scores by counting one correct response for each cul-de-sac not entered on a given trial. When a cul-de-sac was encountered by a rat, two complex stimuli, one from the blind alley and one from the true path, must be discriminated. Entering the blind alley was an error; entering the true path, a success. In the conditioning experiment, when the buzzer was presented, the rat could either respond or not. The former response was a success; the latter, an error. The present paper is concerned with a comparison of learning in the two diverse types of situations in terms of 'success' scores.

RESULTS

Before considering the learning curves of Fig. 1, it is necessary to comment upon the data from which the curves are derived. Let us first examine the maze material. When the total number of errors at each cul-de-sac are tabulated

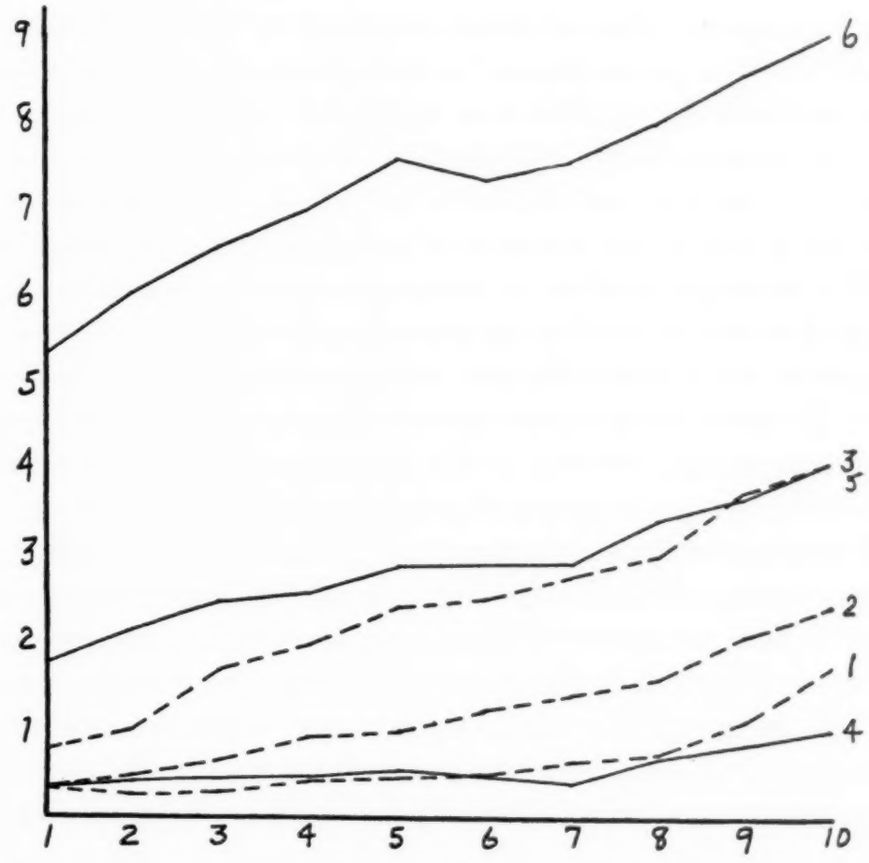

FIG. 1. Vincent learning curves of acquisition for conditioning (broken lines) and maze learning (solid lines). The abscissa values indicate tenths of learning; the ordinate values, number of correct responses. Curve 1 is for conditioning to a limit of 3 successive responses. Curve 2 is for conditioning to a limit of 5 successive responses. Curve 3, broken line, is for conditioning to a limit of 10 successive responses. Curve 4 is for the learning of the first cul-de-sac to the point where this blind is not entered for 3 successive trials. Curve 5, solid line, is for the learning of the first three culs-de-sac to the point where none of these blinds is entered for 3 successive trials. Curve 6 is for learning the entire maze to the point where no blind is entered for 3 successive trials.

for the entire period of training on the maze, the order of difficulty (from most to least difficult) of the 6 culs-de-sac is found to be 1, 3, 2, 4, 5, 6, where cul-de-sac No. 1 is the blind alley nearest the entrance. The actual total error scores are

as follows: Cul 1, 204; Cul 2, 115; Cul 3, 150; Cul 4, 53; Cul 5, 52; and Cul 6, 51. Culs-de-sac Nos. 1, 2, and 3 are of the same order of difficulty, and they are much more difficult than are the remaining three culs-de-sac. The average number of trials required to learn the maze to the point of 3 correct runs in succession was 16.10, sigma 6.20, range 6–30. The average number of trials required to learn culs-de-sac 1, 2, and 3 to the point where for three successive trials no errors were made *in these blinds* was 15, sigma 5.9, range 5–30. The average number of trials required to learn to avoid the first cul-de-sac to the point where no errors were made *in this blind* for 3 successive trials was 10.85, sigma 4.40, range 4–23.

The average number of trials (presentations of the buzzer) required in the conditioning experiment for the rat to make 10 successive runs to the buzzer was 49.1, sigma 29.3, range 21–155. If two extreme cases are eliminated, the average is 44.3, sigma 20, range 21–114. With a criterion of 5 successive responses to the buzzer, the average number of trials for conditioning was 33, sigma 24, range 6–148. With one extreme case eliminated, the average was 30, sigma 17.4, range 6–83. If now we use 3 successive responses to the buzzer as the criterion for conditioning, the average number of trials required was 23.2, sigma 18.1, range 4–117. Eliminating one extreme case, the average was 21, sigma 11.9, range 4–63. (In all of these cases the correct responses, 10, 5, or 3, have been included in the number of total learning trials.) All distributions are slightly skewed towards the zero of trials.

In each case in Fig. 1, the curves are the average of the Vincent curves constructed for the individual rats concerned. (The extreme cases cited in the preceding paragraph are not included in the graphs.) The curves represent in each case the number of correct responses made in successive tenths of learning, and they include the final 3, 5, or 10 responses which constituted the various criteria of mastery. The curves for conditioning also represent the number of correct responses to the buzzer in successive tenths of the learning *time*, because in this experiment the buzzer was presented at one minute

intervals. In the maze experiment the time of each trial was controlled by the rat's behavior and not by the apparatus, and so the abscissa values do not represent equal amounts of time for any given rat. In the face of these differences, the great similarity of the conditioning and maze learning curves becomes greater than if these differences were not present.

Let us now turn to a consideration of the curves in Fig. 1, where the broken lines represent conditioning and the solid lines represent maze learning. (1) All of the curves are essentially linear for the first half of learning. There is no positive acceleration in this part of the curves; and there is no real suggestion of an S-shape in the graphs as a whole. (2) All three maze curves show a plateau from the 5th–7th tenth of learning, although this phenomenon is less apparent in the curve for learning the first cul-de-sac than in the other curves. These plateaus, it should be remembered, cannot represent peculiarities in the experimental and feeding program since they occur in the middle of the learning process and not on specific days or trials. There is no evidence for plateaus in the conditioning curves. (3) In the conditioning curves, the rate of learning is essentially linear throughout, except that the curve for three successive responses (Curve 1) shows an increased rate during the last two tenths of learning.

Curves 1, 2, and 3, for conditioning, show the rates of learning for three different criteria of mastery, 3, 5, and 10 consecutive responses respectively. We can also say that the curves represent the learning of different quantities of identical behavior in contrast to different quantities of diverse material as utilized in such studies as that by Robinson and Darrow (7) where verbal material was used. Thus, in the present experiment, in one instance the rat is trained on giving 10 responses; in another instance, 5 responses; and in the final instance, 3 responses. The respective learning curves give the degree to which 10, 5, and 3 response patterns were approximated in successive tenths of learning. An inspection of the curves indicates that the chief effect on learning of increasing the criterion of mastery is an increase in rate which is revealed by an increase in the slopes of the curves.

The final two tenths of Curve 1 shows an increased slope when compared with the preceding portion of the curve. Does this mean that, where 3 correct responses are the criterion of learning, the final learning rate speeds up; or is the change in rate statistically unreliable? The slope of the curve on the 6th, 7th and 8th tenths may be taken as the difference in the ordinate values of the 6th and 8th tenths; and the slope on the 8th, 9th, and 10th tenths may be taken as the difference in the ordinate values on the 8th and 10th tenths. The average for the former slope is 0.31, sigma 0.78. The average for the latter slope is 1.11, sigma 0.73. The difference between the slopes is 0.80, and the standard error of the difference is 0.15. In other words, the final spurt in this curve is a real one.

Curves 4, 5, and 6 are for the learning of the 1st cul-de-sac, the first 3 culs-de-sac, and all culs-de-sac, respectively. In each case the criterion of mastery was the same, namely, 3 correct runs in succession. (Increases in the total number of trials required for learning and increases in the amount of behavior to be acquired will tend to increase the ordinate values in Vincent curves, but these factors will not affect the form of the curve.) Curves 5 and 6 are essentially alike in form. This is perhaps to be expected since culs-de-sac 4, 5, and 6, the easily learned blinds, are the only ones excluded from Curve 5. Curve 4 has a much lower slope than Curve 5, although both curves are based on the same criterion of learning. Comparing these two slopes, it would again appear that an increase in the quantity of behavior to be mastered brings with it an increase in learning rate. This is further indicated when the slopes of Curves 4, 5, and 6, for the first half of learning, are compared.

Attention should be called to the essential identity of Curves 1 and 4 during the first 8 tenths of learning. Curve 1 represents conditioning to the point of 3 successive responses to the buzzer. Curve 4 represents learning Cul-de-sac 1 to the point of 3 correct responses in succession. A statistical comparison of the slopes of the two curves from the 8th to the 10th tenth of learning indicates that the difference in slope

is a real one. There are insufficient cases available to give a comparison of conditioning and learning the first cul-de-sac to a criterion of 5 correct responses. This is partly because maze training was discontinued when 3 perfect runs had been made and partly because Cul-de-sac 1 was relatively so difficult that errors in it persisted practically to the end of training.

Conclusions

The results of the present study indicate: (1) that the Vincent curves for conditioning in this experiment are linear; (2) that, except for plateaus, the maze curves are also linear; (3) that conditioning to a criterion of 3 successive responses reveals a final increased rate of learning which is not present when 5 or 10 successive responses are the criterion of mastery and which is not present in the learning of the first cul-de-sac of the maze, using as a criterion 3 successive correct responses at the blind; and (4) that an increase in the amount of behavior to be learned brings an increase in the rate of learning as indicated in the slopes of the curves.

This last finding is at variance with the results secured by Robinson and Darrow (**7**) who used human subjects and numbers or nonsense syllables as learning material. It also is apparently at variance with the work of Kjerstad (**5**) who also used human subject. Robinson and Darrow's Tables 2 and 3 show the percentages of material learned in successive sixths of the total learning time. When the data of these tables are plotted, the resulting graphs are essentially linear; but there is no change in the slope with an increase in the amount of material to be learned. It is possible that differences in the scoring of learning in the two cases accounts for the divergence of the findings in the Robinson-Darrow experiment from those which I have here reported.

(Manuscript received December 22, 1934)

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THE NATURE OF ACOUSTIC RESPONSE: THE RELATION BETWEEN SOUND INTENSITY AND THE MAGNITUDE OF RESPONSES IN THE COCHLEA

BY ERNEST GLEN WEVER AND CHARLES W. BRAY

Princeton University

Since 1930, when we first described the electrical responses which arise on stimulation of the ear by sound, evidence has accumulated which makes it possible to recognize in this phenomenon a number of component stages. These include the cochlear response, the auditory nerve response, and a series of responses which appear in the central nervous system as impulses are conducted over successive fibers in the auditory pathways. In our previous work we have studied a number of these stages of the general phenomenon, but have dealt in greatest detail with the auditory nerve responses. In this investigation we shall consider (1) the functional relationship between cochlear response and sound intensity, and (2) the changes in this relationship as frequency varies.

There is abundant evidence that the cochlear responses are of a physiological character and that they reflect the essential operations of the end-organ. Of particular significance in this regard is the discovery by Howe and Guild that the cochlear responses, as well as all nervous effects, are absent in cats in which the organ of Corti is lacking or seriously defective.[1] From such observations we may conclude that the cochlear responses arise in the sensory cells of the organ of Corti as these cells are acted upon by sound. Therefore, these responses may be used to study the sensory portion of

[1] H. A. Howe and S. R. Guild, Absence of the organ of Corti and its possible relation to electric auditory nerve responses, *Anat. Rec.*, 1932–33, **55**, Suppl., 20–21; H. A. Howe, The relation of the organ of Corti to audio-electric phenomena in deaf albino cats, *Amer. J. Physiol.*, 1935, **111**, 187–191. See also, H. Davis, A. J. Derbyshire, M. H. Lurie, and L. J. Saul, The electric response of the cochlea, *Amer. J. Physiol.*, 1934, **107**, 324–326.

the auditory system and to determine its role in the process of hearing.

Apparatus and Procedure

In these experiments the guinea pig has been used as the experimental animal, largely because of the completeness of our knowledge of the anatomy and acuity of its ear.[2] The animal was maintained under Avertin anesthesia, and after an incision behind the ear the bulla was opened to expose the round window. On the round window was placed a minute electrode of silver foil or platinum wire, while an inactive electrode was placed on skin or muscle tissue nearby.

The animal was placed in a sound-proof, electrically shielded room, with the meatus of the operated ear at a standard distance from a tube through which tonal stimuli were delivered. The stimuli were produced by electric methods. The electric currents from an oscillator were filtered to remove harmonics, controlled in intensity by attenuators, and delivered to a Western Electric 555 receiver which worked into the tube mentioned above. The receiver was outside the sound-proof room, and the tube ran through an opening in the wall.

The intensity of the stimuli was measured in units of rms pressure (bars = dynes per sq. cm.) by placing a calibrated condenser-transmitter in the position normally occupied by the ear of the animal. The accuracy of this method of measurement, as determined by repeated tests, is within 5 db. This figure takes into account the variations caused by ordinary changes in position of the animal's ear with respect to the tube through which the stimuli were delivered.

The purity of the stimuli was tested by leading the amplified output of the condenser-transmitter into a cathode-ray oscillograph. The waves as observed were all of simple sine form, except for 100~ and 200~ at their highest intensities. These two tones showed slight distortion at intensities of 10 bars or more.

The voltages produced at the electrodes were amplified and

[2] See G. P. Horton, A quantitative study of hearing in the guinea pig (Cavia cobaya), *J. Comp. Psychol.*, 1933, **15**, 59–73.

led to the cathode-ray oscillograph. The absolute sensitivity of the recording system was such as to make possible the observation of voltages of 0.3 to 0.4 microvolt (μv.). The amplifier was devised to give a gradually increasing sensitivity for higher frequencies, from 0.4 μv. at 100~ to 0.3 μv. at 10,000~. This sensitivity was only slightly impaired by a fairly constant background of stray electrical effects from the animal. Insofar as this background was constant in magnitude it was taken into account in our measurements. Occasional variations, however, introduced errors. These errors can be neglected for measurements above 10 μv.

The general procedure for each animal consisted of the presentation, in various orders, of a number of tones of frequencies between 100 and 10,000~. Each tone was first presented at a low intensity, and then raised by steps of 5 or 10 db until the maximum output of our apparatus was reached. For each step of intensity the magnitude of the cochlear response was measured in terms of the maximum amplitude at the oscillograph. From these observed values we have computed the rms values of voltage at the electrodes. These computations took into account all characteristics of the recording apparatus.

Care was necessary in these observations because of the frequent occurrence of a phenomenon which we have called a protective reflex. The phenomenon appeared as diminutions in the magnitude of the response during constant stimulation. These diminutions appeared occasionally for moderate intensities, and fairly frequently for high intensities. They were observed more often for low than for high tones. The amount of diminution varied in different instances from a just observable change to a complete disappearance of the response. The duration was usually about one second, but in a few instances amounted to several seconds. We tentatively assume this phenomenon to be a result of reflex contraction of the muscles of the middle ear. A further study is being made of it.

In addition to the procedure outlined above, tones beyond 10,000~ were usually presented to ascertain the upper limit

of cochlear responses, but no quantitative study was possible for such tones because of the restricted range of calibration of our condenser-transmitter. These tests revealed the presence of responses up to 25,000~, with faithful reproduction of the frequency and form of the sound waves.

Results

The procedure outlined above was applied to 7 guinea pigs. Seventeen frequencies between 100 and 10,000~ were used, though not all were studied in any given animal.

The results showed the nature of the relationship between intensity of stimulus and intensity of cochlear response for representative frequencies throughout the greater part of the auditory range. Space does not permit the presentation of these results in full, but typical curves showing the intensity relationship are given in the first three figures. It should be noted that logarithmic scales have been used in these figures for both stimulus and response, in order more conveniently to represent their variations over wide ranges. Smooth curves have been drawn through the observed points to give the best fit as determined by inspection.

Figure 1 shows the responses of 5 animals when stimulated with a tone of 100~ at various intensities. Figure 2 shows similar results for 5 animals with a tone of 1000~, and Fig. 3 for 6 animals with a tone of 4000~. The curves as shown are straight throughout the greater part of their course but in most instances bend over sharply for the higher intensities of sound. This bending occurred for every frequency except 100~, and probably would have occurred for this tone also if greater intensities had been available.

The curves of the various animals at each frequency are in good agreement as regards both sensitivity and slope. The degree of sensitivity of a given animal is indicated by the general position of its curve with reference to the abscissa. A curve which runs to the left of the group indicates relatively high sensitivity, one which runs to the right relatively low sensitivity. As shown, the differences of sensitivity among the animals are seldom greater than 10 times, or 20 db. The

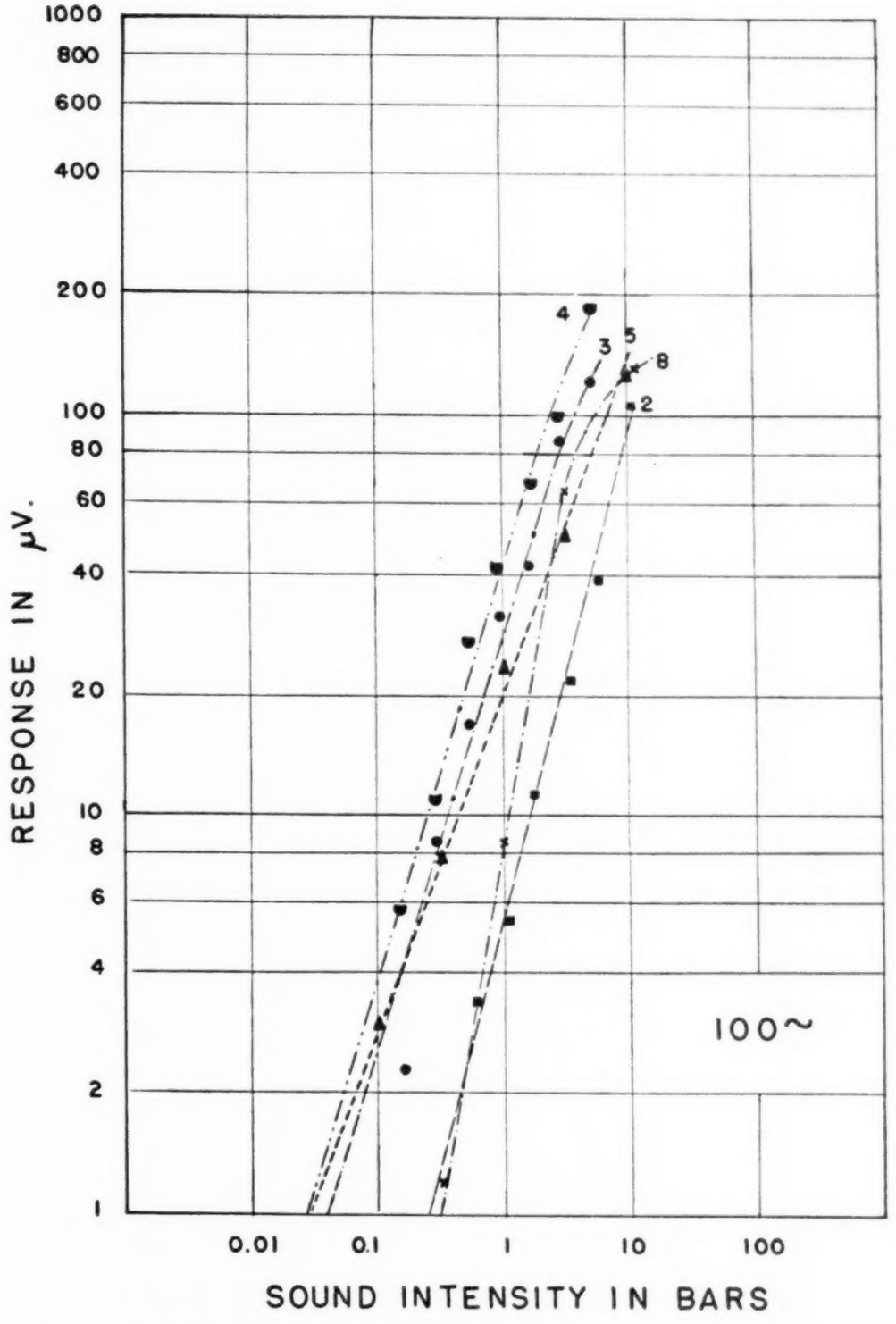

FIG. 1. Intensity functions, showing the relation between sound intensity and cochlear response for 100~. The numbers at the top of the curves designate particular animals.

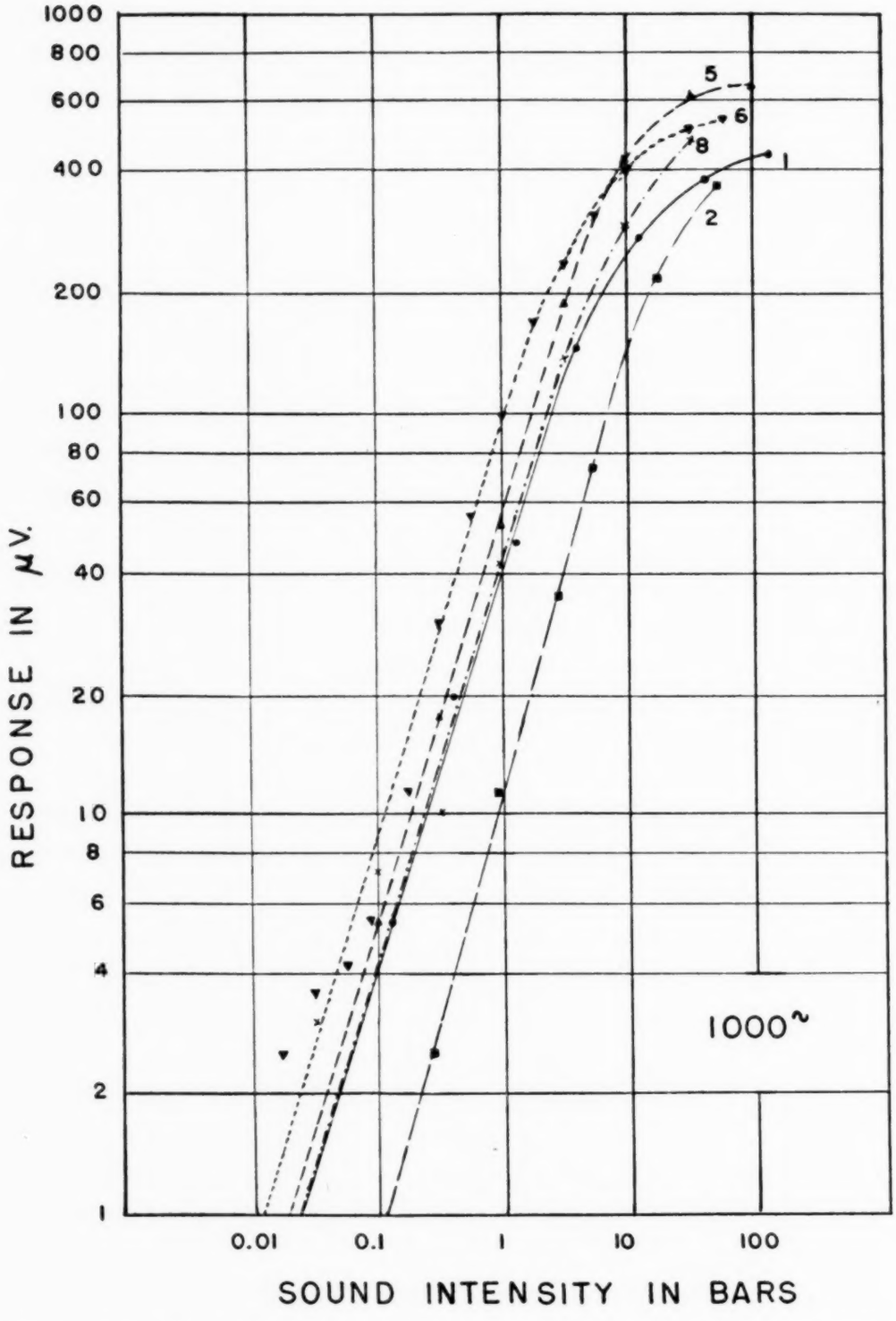

FIG. 2. Intensity functions for 1000~. The numbers at the top of the curves designate particular animals.

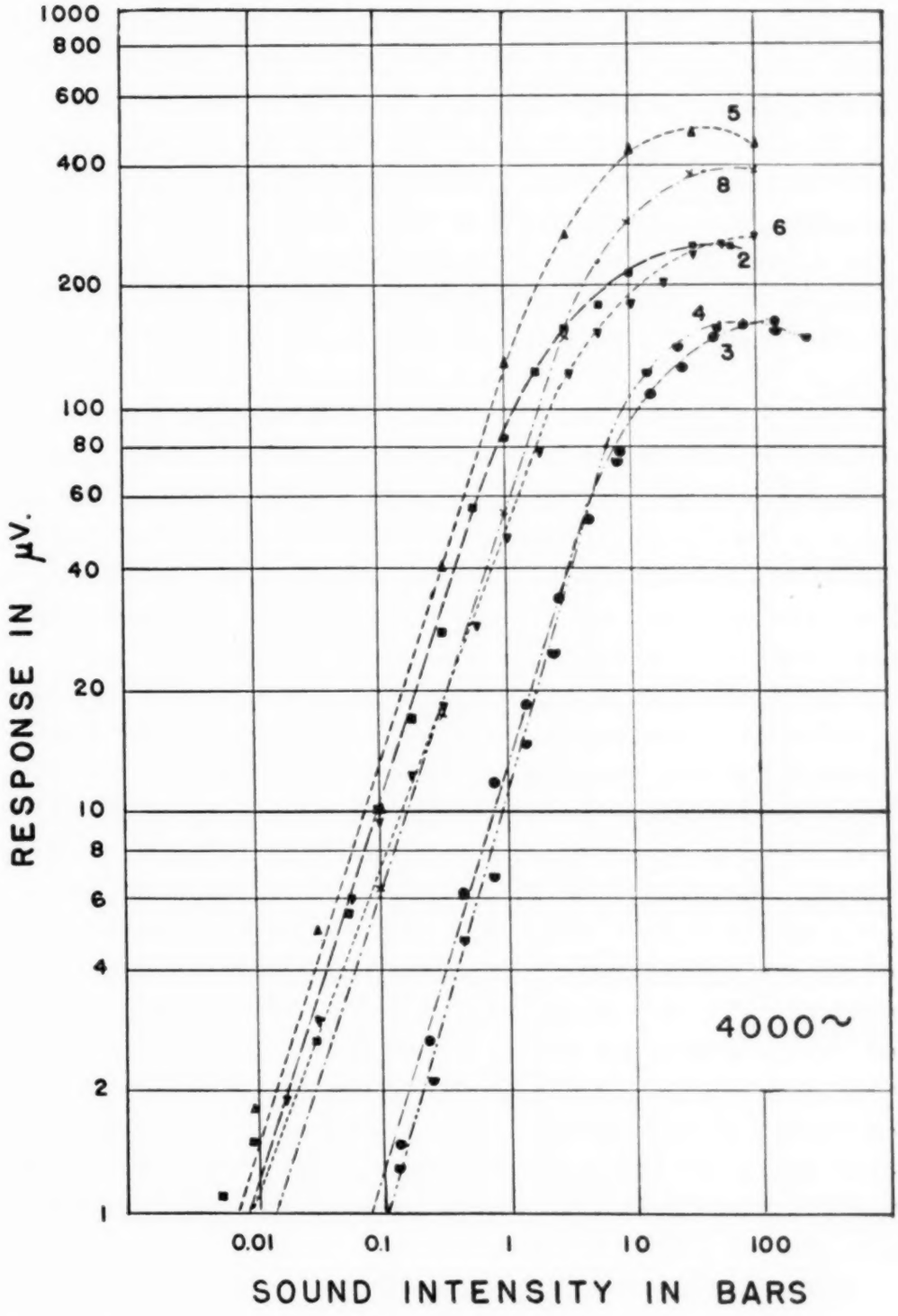

FIG. 3. Intensity functions for 4000~. The numbers at the top of the curves designate particular animals.

relative sensitivity of a given animal varies considerably from one frequency to another. For example, animal No. 2 is the least sensitive of the group at 100~ and 1000~, but shows relatively high sensitivity at 4000~.

With a few exceptions, the curves of the several animals have closely similar slopes. The most marked variations for any one frequency occurred at 100~, and are shown in Fig. 1. The degree of agreement among the curves for different frequencies for a single animal is shown in Fig. 4. In this figure six functions for tones between 100~ and 10,000~ are shown for animal No. 5.

Figure 4 also shows a significant difference in the relative position at which bending occurs for the various frequencies of sound. In general, the curves for the high tones bend and reach a maximum at lower values of response than do the curves for the low tones. The position of the 100~ tone in this relation could not be determined because greater intensities were not available, as mentioned above.

The variations of sensitivity of a given animal for tones of different frequency, as indicated in Fig. 4 by the general positions of the straight portions of the curves, can more clearly be brought out by a different manner of plotting the data. In Fig. 5 results such as those of Fig. 4, but for another animal, are shown in the form of equal-response curves. Each of the curves shows the sound intensity necessary to produce a given amount of response at various frequencies between 100~ and 10,000~. The values of response selected for these calculations are at approximately equal logarithmic steps between 1 μv. and 540 μv., which gives a fairly uniform separation of the curves. The irregularities that appear at some points for the uppermost curves reflect the fact shown in Fig. 4 that the intensity functions for different frequencies bend over at different places.

It should be noted that the lowest curve in this figure does not represent an absolute threshold for the cochlear response. Indeed, no such threshold occurs within the range of sensitivity of our apparatus, and it is questionable whether any true threshold exists for this response.[3]

[3] The 'thresholds' that have been reported in the literature are most likely expressions of the limitations of recording apparatus. Consider, *e.g.*, H. Davis and others, *Amer. J. Physiol.*, 1934, **107**, pp. 322 ff.

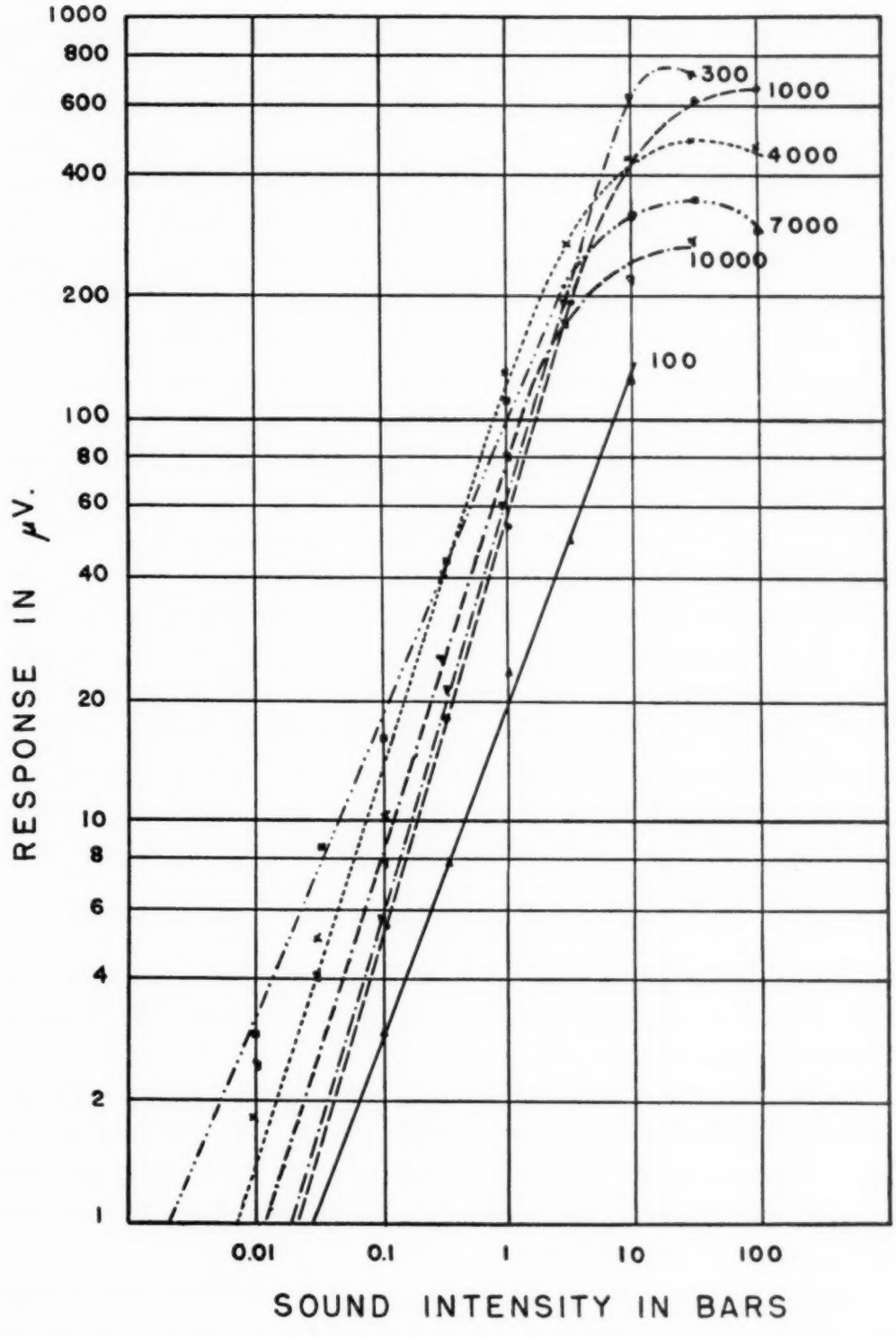

FIG. 4. Intensity functions for animal No. 5. The numbers at the top of the curves indicate sound frequencies.

An examination of Fig. 5 reveals fairly regular changes of sensitivity as frequency varies. For this animal, the greatest sensitivity, for weak responses, lies in the neighborhood of 600~, with a secondary region of relatively high sensitivity around 6000~. These two regions probably indicate mechanical resonances of the ear. On either side of them the sensitivity falls off rather rapidly. The area between 1000~ and 3000~ is somewhat uncertain in this animal, as no frequencies were studied within these limits. However a consideration of the general trends of the curves, and of results in other animals, indicates that the lines as drawn are approximately correct.

If the curves for low and for high magnitudes of response are compared, it is observed that the relative sensitivity for different frequencies is a function of response level. As the level of response is changed from low to high values, the curves become flattened. The marked resonance near 600~ at 1 μv. practically disappears when 300 μv. is reached. Other more complex changes occur in the region 4000–8000~.

Curves of the type shown in Fig. 5 vary in details of form in different animals, but all the cases here studied showed the greatest sensitivity in the region between 300~ and 900~. Moreover, all cases showed flattening of the curves at high levels of response.

Discussion

The results presented above may now be considered in their relation to the action of the cochlea and the general process of hearing.

Curves such as those shown in Figs. 1–3 show two distinguishable features of cochlear response as a function of intensity. The first and most important is indicated by the straight portions. The second is the rapid bending of the curves at high intensities.

Let us first consider the straight portions. Curves which are straight when plotted on logarithmic coördinates, as in these figures, are power functions, expressed by an equation of the form

$$E = k\,P^a.$$

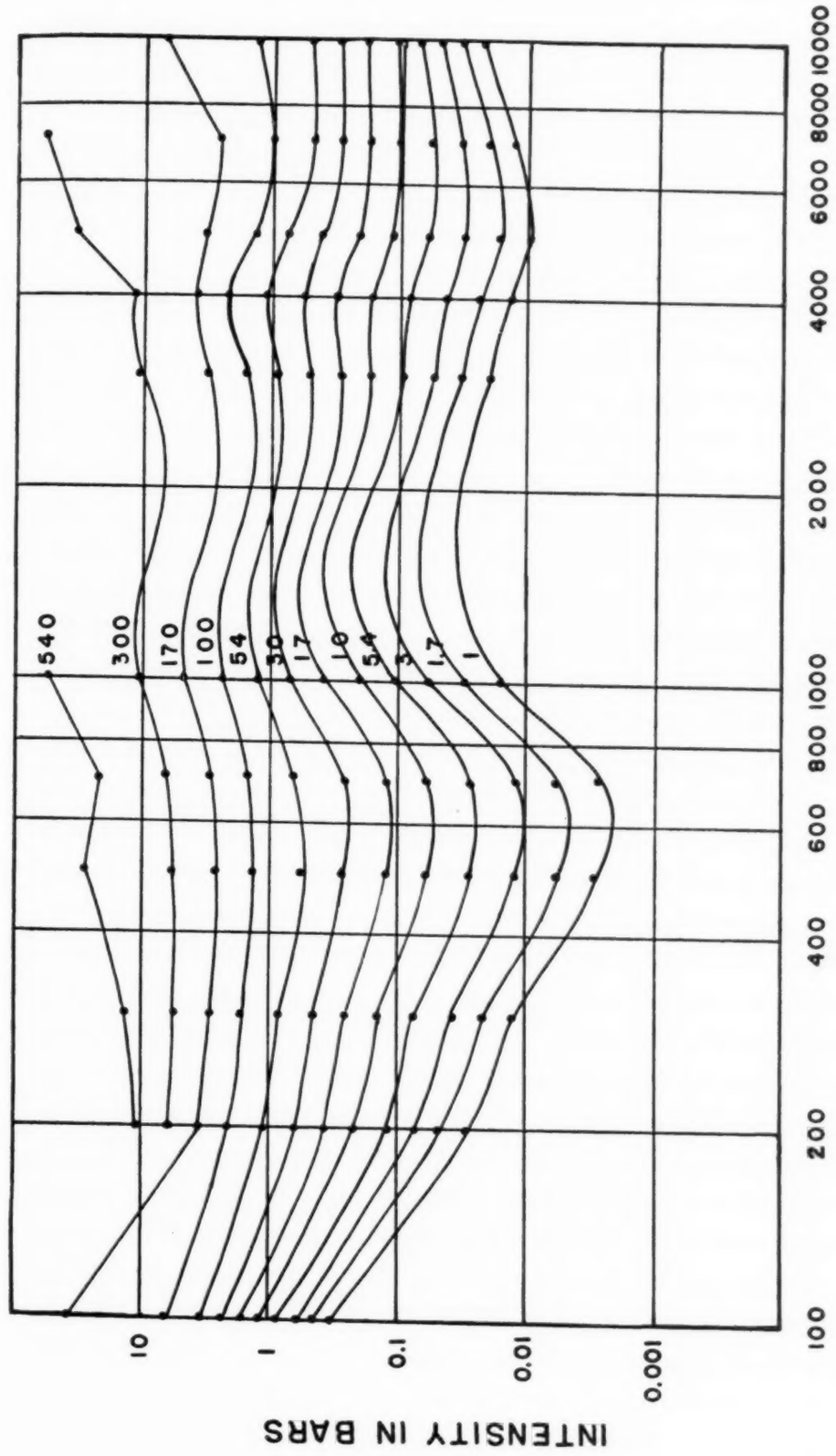

FIG. 5. Equal-response curves for animal No. 8. Each curve shows, for various frequencies, the intensity of sound necessary to produce a given magnitude of response. The magnitude of response represented by a given curve is stated in μv. by the number above the curve.

Here, E = electrical potential of the cochlear response in micro-volts, P = the pressure of the sound stimulus in bars, the exponent a = a constant for any one curve, determined by its slope, and k = a constant which expresses that value of E for which $P = 1$. If in this equation the exponent $a = 1$ the function becomes linear.

A determination of the exponent a for our curves showed values which for most frequencies were equal to 1, within the range of experimental error. The higher frequencies, 4000˜ and above, showed values of a which sometimes were equal to 1, but occasionally were significantly less than 1. A calculation based on one of the curves for 4000˜ gave the equation

$$E = 55\ P^{0.93}.$$

Similar calculations from data for 7000˜ and 10,000˜ gave values of a which in four cases equaled 1, in three cases equaled 0.8 and in one instance was 0.55. Two cases were found for 100˜ where a was noticeably greater than 1. We are not able at present to offer a complete explanation of these divergences of the functions from linearity. The divergences at 100˜ may be related to the considerable distortions of wave form of the response which occurred at this frequency. The divergences at the higher frequencies, however, arise from no such cause, as the waves were of simple sine form for all but the highest intensities. Further investigation is being made of this feature of the results.

Studies of the relation between cochlear response and sound intensity have previously been reported for the cat by Davis and his collaborators.[4] Their data were graphed with sound intensity in logarithmic terms and response in arbitrary linear units; the result was a sigmoid curve. In one place, they stated that the functional relation between cochlear response and sound intensity is 'neither linear nor logarithmic.' In a later description of these data, however, Davis has stated that the function is roughly linear at very low intensities of stimulus and more nearly logarithmic at stronger

[4] H. Davis and others, *Amer. J. Physiol.*, 1934, **107**, p. 321; H. Davis, A. J. Derbyshire, and L. J. Saul, Further analysis of the electrical phenomena of the auditory mechanism, *ibid.*, 1933, **105**, 27–28.

intensities.[5] Actually, the results obtained by Davis and his co-workers are of the same type as those presented in this paper. On a logarithmic graph their curve would be straight at low and moderate intensities, and bent at high intensities. It seems likely that these writers, in considering the question of linearity, failed to take into consideration the scales used in plotting their data. When the proper units are used, it may be shown that the functional relationship observed by them is the same, or nearly the same, as that described here. The precise degree of resemblance between their results and ours cannot be ascertained because of their use of arbitrary units to represent the magnitude of response.

Davis has discussed his results in relation to the common view that non-linear distortion in the peripheral mechanism of the ear is the source of subjective tones in auditory perception.[6] His interpretation that non-linearity exists for all but the lowest intensities of sound means that subjective tones should occur at moderate as well as at high intensities. In our results, at any rate, harmonic frequencies were not introduced until the intensities reached high magnitudes (except for 100~ for which harmonics were generally present). In the region where our curves begin to bend over, the waves as observed on the oscillograph lost their simple sine form, and became noticeably distorted.

Davis has concluded further that the Weber-Fechner relationship in hearing makes its appearance in the peripheral mechanism of the ear. He has described the relationship between stimulus and cochlear response as 'something similar' to this law.[7] This conclusion, like that regarding subjective tones, is not supported by our results. A linear function, or even the power functions ($a \neq 1$) shown in a few cases, will not lead to a Weber-Fechner (logarithmic) relationship between sound intensity and loudness. The source of this relationship must be sought in processes interposed between

[5] H. Davis, in C. Murchison, *Handbook of general experimental psychology*, p. 972; H. Davis, The electrical phenomena of the cochlea and the auditory nerve, *J. Acoust. Soc. Amer.*, 1935, **6**, p. 210.

[6] H. Davis and others, *Amer. J. Physiol.*, 1934, **107**, 320–321; Davis, in Murchison's *Handbook*, p. 972.

[7] H. Davis, in Murchison's *Handbook*, p. 973.

the cochlear response and auditory perception. The existence of such processes is indicated by results obtained by Hughson and Witting.[8] Their results show that the relationship between stimulus and auditory nerve response is different from the one exhibited by the simple cochlear response.

The above discussion has been concerned primarily with the straight portions of our curves. Let us now consider the bent portions. Two features require explanation. One is the fact of bending itself, the other the difference in maximum level of response attained by tones of different frequencies. For the explanation of bending three possibilities suggest themselves. The first is that at high intensities of sound there occurs a reduction in efficiency of the mechanical transmission system of the middle ear. The second is that overloading occurs in the action of the sensory cells of the organ of Corti. Let us assume that the electrical effects observed at the round window are produced as a result of mechanical deformation of these cells. Then, as the intensity of sound is increased, some value will be reached beyond which the deformation of the cell ceases to increase in proportion to the pressure. A related condition here is the capacity of the cell to produce electrical effects, which obviously must be limited. The third possibility is that there is a limit to the number of sensory cells available in the action of any sound frequency. A response cannot increase beyond the value where all the cells accessible to its stimulus are acting to their maximum extent.

These three possibilities are not mutually exclusive, but may act jointly. The third possibility just mentioned, when added to the assumption that high frequencies involve relatively restricted regions of the basilar membrane, will explain the fact shown in Fig. 5 that the cochlear functions for high frequencies attain a maximum at lower levels of response than do the low frequencies.

The simplest explanation of the origin of the cochlear response is that it is a direct result of the action of mechanical pressures upon the sensory cells of the organ of Corti, and is

[8] W. Hughson and E. G. Witting, An objective study of auditory fatigue, *Acta otolaryngol.*, 1935, 21, 457–486.

not a release of energy such as that which occurs in the action of nerve fibers. This explanation follows from the fact that cochlear response bears a simple relation to sound intensity. The most general condition, in which cochlear response is a linear function of sound intensity, indicates further that the peripheral mechanism of the ear is a very faithful device for the conduction of acoustic energy and its conversion into electric effects.

According to our view, the sensitivity curves for the cochlear response, as those of Fig. 5, represent the essential activity of the end-organ. It must be kept in mind, however, that the sensitivity exhibited at this stage in the process of hearing is not necessarily the same as that which may be shown by other methods, such as conditioned response tests, reflex or behavioral tests, and the like. Such tests as these involve additional features of the auditory mechanism, as well as characteristics of the integrational and reaction systems of the animal. Nervous processes, in the cochlea and at various levels in the auditory pathways of the central nervous system, are in a sense superimposed upon the processes which the cochlear response reveals. For a complete analysis of the function of hearing, therefore, we need more data of the type presented here, obtained from various levels in the auditory system.

Summary

The relation between the intensity of stimulus and the magnitude of cochlear response has been studied in the guinea pig for representative tones from 100 to 10,000~. For all but the high intensities of sound, this relation in most instances is linear, but cases were found in which it is better expressed as a simple power function. These results show that the source of the Weber-Fechner function must be sought in processes beyond those revealed by the cochlear responses.

At high intensities the relation between stimulus and response changes rapidly until a maximum response is reached. This change in the form of the function is marked by the introduction of harmonic frequencies, which fact may explain the rise of subjective tones in auditory perception.

(Manuscript received January 31, 1936)

REACTION TIME AND CONDITIONING: FIRST STUDIES

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When an attempt is made to describe (or explain) human learning in terms of conditioned responses, two assumptions are made: (1) that conditioning as observed experimentally in dogs is characteristic also of human beings, and (2) that voluntary as well as reflexive acts are capable of being conditioned. The first assumption is supported by a certain amount of both experimental and observational evidence, although the experimental support is not unequivocal. Particularly is there a paucity of evidence to show that the associated phenomena—experimental extinction, automatic recovery, disinhibition, external and internal inhibition, etc.—are characteristic of human subjects. The second assumption is, as far as the author is aware, without experimental support.

The studies to be reported here are a first attempt to put the second assumption to an experimental test, to discover whether voluntary acts may be conditioned. In making this test, evidence as to whether the associated phenomena are exhibited by human individuals was also obtained.

Theoretical Considerations in Setting up the Experiment

An examination of the available experimental data has led the writer to reformulate the fundamental requirement for conditioning as follows: "The essential requirement for conditioning is that a stimulus regularly precede a response, whatever the cause of that response." [1] "A Stimulus gains effectiveness for a given response when the stimulus is followed by that response as a dominant response." [2] "The develop-

[1] *General Psychology for College Students*, Macmillan, 1929, p. 154.

[2] Outline of the conditions under which learning occurs, *Psychol. Rev.*, 1932, **39**, p. 176.

ment of a conditioned response involves a sequence of secondary stimulus and dominant response rather than a pairing of secondary and trip stimulus."[3] These assertions imply both assumptions mentioned at the outset and are quoted because they clearly indicate that the chief problem in setting up an experimental test is the selection of some response which may be repeatedly evoked at the will of the experimenter and which will be made as a dominant response. The response made in reaction time studies seems to meet these requirements. If the subject can be induced to strive for the quickest possible reaction (to beat his own or other's record or for any other reason), his response will be dominant and it can be evoked when desired and as often as desired. In a study of conditioning it seems desirable, however, to select a response which may be exhibited in varying amounts, and accordingly the response finally selected was a complete turn of a handle with time measured from the onset of the primary stimulus to the start of the turn.

The technique in training a subject to make this turn as a conditioned response would be the regular method, the presentation of a secondary stimulus followed by the primary. The difference from studies of conditioned *reflexes* would be that the subject in this case would react to the primary stimulus from 'instructional necessity' rather than 'reflexive necessity.'[4]

The presence of conditioning and the associated phenomena may be tested for by techniques closely analogous to those employed in the more conventional studies. For the various test presentations the following data become available: (1) the number of degrees through which the handle is turned, (2) observable preparations for turning the handle, and (3) the reaction time. The second and third types of data are to be classed as indications of the readiness to react, but the author would insist upon their admissibility as evidence of conditioning, inhibition, etc. That the conditioned reflex is best conceived as a conditioned readiness

[3] An examination of conditioned reflex theory, *Psychol. Rev.*, 1933, 40, p. 460.

[4] It is interesting in this connection to review the concept of reflex presented by Pavlov in his *Conditioned Reflexes*, Oxford Press, 1929.

to make the response originally belonging to the primary stimulus seems clear from an examination of the experimental data.[5] That reaction time is an index of readiness to react may possibly be debated, but the writer trusts that it is generally accepted.

To facilitate description of the techniques employed in the present experiments, a set of symbols may be given. Let S stand for the secondary stimulus, P for primary, E for extra stimulus, O for omission of stimulus,—for the time interval between stimuli, and ( ) for preceding presentation. Thus $S-P$ is the standard or training presentation; $S-S$ is one test for conditioned response; $(S-S)S-P$ and $(S-O)S-P$ are tests for extinction, etc.

Preliminary Study

Before setting up apparatus to control the presentation of stimuli and to measure reaction time, it seemed worth while to make a preliminary determination of how readily conditioning is set up as indicated by an $S-S$ test. For this determination the presentation of stimuli was controlled manually, each stimulus lasting approximately a half second and the interval between secondary and primary being about three seconds. Eighteen naive subjects were used, and for half the group an electric light served as the primary and a buzzer as the secondary, while for the other half these stimuli were interchanged. After each subject was trained with twelve standard presentations, an $S-S$ test was given. On this test, *i.e.* upon the presentation of the second S, ten subjects turned the handle, the turns varying from a bare start to a complete turn. All subjects were given ten more standard presentations and then a second $S-S$. On this test the same ten subjects again responded positively. In the case of the eight who had not responded, an intermission was next taken and the experimenter urged them to react more quickly if possible. Each was then given eight standard presentations and a third $S-S$. On this five of the eight responded, making a total of fifteen of the eighteen who

[5] See article last cited.

eventually responded positively. Of the fifteen, seven were in the group for which the light served as primary and eight in the group for which the buzzer was the primary.

In this preliminary stage Professor McGeoch kindly consented to act as a subject and to make suggestions for the final experimental set up. At first the light was used as primary and later the buzzer as primary. In both cases he responded positively to the $S-S$ test.

These preliminary studies made it clear that a large percentage of subjects could be trained to make a conditioned turn, and it also seemed clear to the experimenter as he observed the subjects that the $S-S$ test had a marked inhibitory or extinguishing effect which would readily show in reaction time measurements. Professor McGeoch completely omitted the response to the primary occurring next after the test, with the later report that there was an utter blankness which changed over to astonishment.

Apparatus

The apparatus available was not all that could be desired, but it has proved satisfactory for a first study. (Highly satisfactory apparatus has now been secured and further study is in progress.) A Cenco impulse counter has been employed to measure reaction time. This instrument is accurate and highly dependable. It gives readings in 1/120ths of a second when connected into a controlled A.C. line. (All results are given in these units.) A rotor and a ten contact stator were placed on a shaft of an old phonograph spring motor and the speed of the motor adjusted to give second intervals between contacts. By means of switches in the stator leads, any stimulus could be made to come in even seconds before or after any other stimulus or combination of stimuli. In standard presentations the interval between the onset of the secondary and the onset of the primary was three seconds. The secondary (or any stimulus coming at the regular time of the secondary) lasted 1/3 of a second, while the primary (or any coming in its place) lasted until the subject turned the handle or until the experimenter broke the circuit. Both the interval between and the duration of the stimuli were quite constant when checked by the impulse counter. The most undesirable feature of the apparatus was that the interval between presentations was constant, always seven seconds. Another was that the duration of the primary was dependent upon the reaction time of the subject.

The control apparatus was situated back of the subject where the experimenter could introduce the modified presentations and observe the subject. The impulse counter was placed in another room where it could not be heard by the subject, and it was read by an assistant.

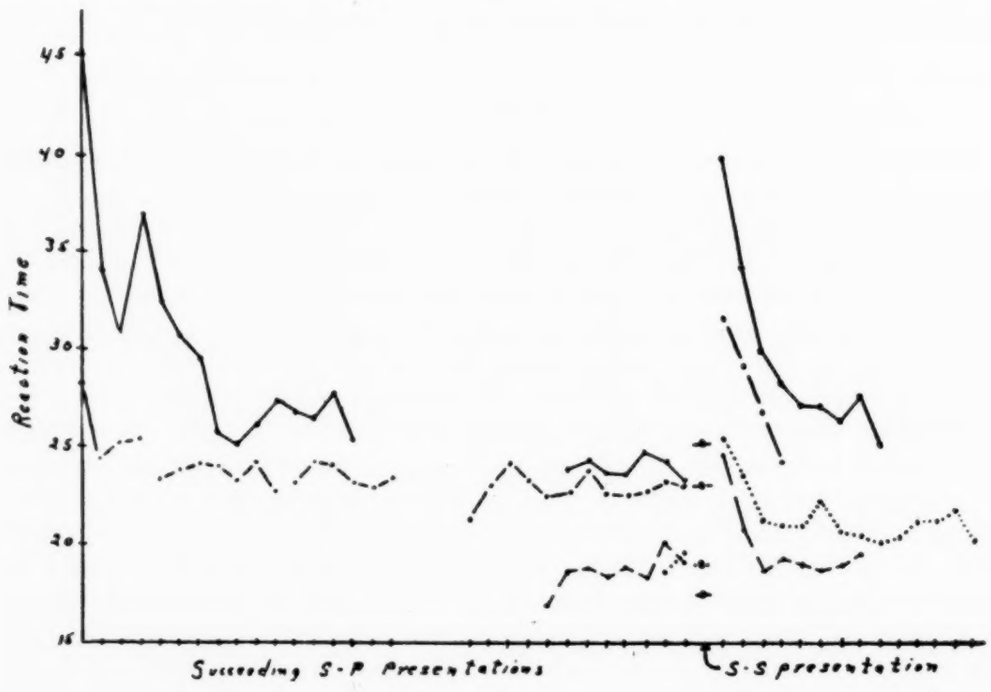
Procedure

Four groups of ten subjects were used, and all were members of the author's beginning class. For all groups an electric light was used as primary and a buzzer as secondary. After a subject was properly instructed, she was given fifteen standard presentations and then a short intermission (while the experimenter wound the motor). After the intermission there were eight standard presentations, then an $S-S$, and then eight more standards. On the second day there were four standards, then a seventeen second interval ($O-O$) instead of the usual seven, then seven standards, another $O-O$, and six more standards, intermission, twelve standards, an $S-S$, and four standards. After the second day the procedure varied according to the group. In general each subject was given two sets of fifteen standard presentations each day, with a modified presentation occurring somewhere in each set. Subjects appeared three times a week until they had records for twelve days.

Results

A. For the First Two Days

The unbroken line of Fig. 1 shows the average performance of all subjects for the first day. Each point is the average



reaction time for an $S-P$ presentation, while the upper large dot toward the right is the reaction time of the 21 subjects who turned on the $S-S$. This presentation has a marked disruptive influence on succeeding $S-P$ presentations, giving rise to reaction times practically as slow as those at the beginning of the experiment. The first row of Table 1 shows

the reaction time on the $S-S$ presentation in comparison with the average $S-P$ reaction times after intermission, excluding the two $S-P$'s immediately after the $S-S$. It also shows the number of subjects who made a turn. The second row of Table 2 shows the disruptive influence of the $S-S$. The reaction time on the first $S-P$ after the $S-S$ is 13.7/120ths of a second slower than the average $S-P$ reaction time, and 33 of the 39 subjects showed slowness on this reaction. The reaction of the second $S-P$ after the $S-S$ was 8.1/120ths of a second slower than the average, and 30 of the 39 subjects exhibited slowness on this $S-P$.

The performance for the second day is shown by the broken line of Fig. 1, by row 2 of Table 1, row 3 of Table 2, and row 1 of Table 6.

B. Simple Conditioning

In Table 1 are brought together the data showing conditioning in its simplest aspect. In all tables the number of

TABLE 1

CONDITIONING

Presentation	Dif.	No. Sub.	Day
$S-S$.....	−1.2	21/39	1
$S-S$.....	− .7	28/40	2
$S-E$.....	−2.5	11/20	3
$S-E$.....	−3.8	15/20	7–8
$S-S$.....	−1.9	30/40	8–9
$S-E$.....	− .1	28/39	9–10
$S-S$.....	−1.6	33/39	12
$O-P$.....	50.9	40/40	3–5
Con. $O-P$.....	6.0	39/39	12

subjects indicated for $-S$ and $-E$ presentations is the proportion who turn on these presentations, while for $-P$ presentations the proportion indicates the number who show a difference in the direction (plus or minus) shown in the preceding column. Thus the 21/39 of row 1 of Table 1 indicates that 21 of the 39 subjects turned on this $S-S$ (not that this number were faster on this presentation), while the 39/39 of the last row of Table 1 indicates that the reaction

time of 39 out of the 39 subjects was slower on this presentation than on the regular $S-P$ presentations.

An examination of the table shows that an increasing proportion of subjects respond on the $S-S$ as training is increased. It is also to be noted that as many turn when the bell (E) is substituted for the light (P) as when the buzzer (S) is substituted. This may at first seem to be contrary to expectations derived from Pavlov's results, but the writer takes it to mean that the presentation of an S induces a readiness to respond to the P and that any stimulus will transform this readiness into overt turning. (In further study an S will be followed by a touch stimulus.) It is noteworthy that the reaction time on the $S-S$ and $S-E$ tests is in all cases slightly faster than the average $S-P$ reaction time. Three factors probably play a part in this. $S-S$ and $S-E$ presentations are followed by slowed reactions and only the two succeeding $S-P$ reaction times were omitted in calculating the average. Again there is at first a tendency for those subjects whose reaction times are slow not to turn on the $S-S$. Finally, the $S-S$ will be responded to only in case the individual is highly ready to respond, and the more ready, the shorter the reaction time. A subject will accordingly turn only if the $S-S$ occurs at a point at which the subject would have achieved a short reaction time if a regular $S-P$ had been given. This fact will account for the second fact that not all subjects respond to the $S-S$ even on the twelfth day. Every one of the subjects responded to at least one of the four $S-S$ tests.

If the secondary serves to make the individual ready for the P as indicated for the $S-S$ and $S-E$ test results, then the absence of the S should make him less ready than he would have been without training. That this is the case is shown in the $O-P$ results of Table 1. Training leads the subject to expect the P after the S and only after the S.

The last row of Table 1 shows results for a special series after the termination of the experiment proper. Each subject was told that there would be no S in this special test and was then given fifteen presentations of the P at the regular ten

second intervals. The difference between the speed of these reactions and the terminal $S-P$ reactions, 6/120ths of a second, indicates the difference in readiness resulting from the presentation of the S and the readiness achievable when the subject attempts to hold himself in a high state of readiness. It seems fair to hold that any decrease in speed of reaction greater than this 6/120ths of a second must be attributed to an inhibitory effect of some sort or to a lack of readiness resulting from training, as for example, the lack of readiness shown on the regular $O-P$ test. This value is perhaps a fairer guide in interpreting results than is the standard deviation.

C. Experimental Extinction

The extinguishing or disruptive effect of the $S-S$ presentations of the first two days has already been mentioned. In Fig. 1 this effect for $S-S$ presentations on the 9th and 12th days is also shown. This figure shows quite clearly the decrease in extinguishing effect as training is increased, a result to be expected from Pavlov's work. Table 2 gives results for

TABLE 2
EXTINCTION

Presentation	Dif. 1	No. Sub.	Dif. 2	No. Sub.	Day
$(S-O)S-S$.....	1.6	13/39			4
$(S-S)S-P$.....	13.7	33/39	8.1	30/39	1
$(S-S)S-P$.....	8.7	37/40	6.3	33/40	2
$(S-E)S-P$.....	7.6	18/20	4.5	15/20	3
$(S-O)(S-S)S-P$.....	7.0	35/39	4.7	32/39	4
$(S-O)(ES-S)S-P$.....	7.9	35/39	1.7	29/29	4
$(S-O)S-P$.....	4.9	30/40	3.7	28/40	6
$(S-S)S-P$.....	4.5	31/40	2.6	27/40	7–9
$(S-O)S-P$.....	7.8	32/40	2.8	31/40	8–10
$(S-E)S-P$.....	8.5	32/39	3.2	29/39	9–10
$3(S-O)S-P$.....	6.5	14/18	1.8	11/18	10–11
$(S-S)S-P$.....	5.5	34/39	1.7	28/39	12

these and other extinguishing presentations. The decrease with training is revealed more markedly on the second $S-P$ after the modified presentation than on the first.

The apparent equality of $S-S$, $S-E$, and $S-O$ presentations in producing disruptive effects would seem to indicate that the effect comes from the omission of the P at the ex-

pected time rather than from any stimulation substituted for the *P*, *i.e.* that the effect is a true extinctive effect. To confirm this apparent equality an *S*—*O* will in further experiments be introduced early in training, but the experimenter has no doubt that it will show an effect as great as an *S*—*S* at the same stage of training. Occasionally a subject during the first few days would lift the handle off the contact point, causing an omission of the *P* which the experimenter had not intended, and on these occasions the disruptive influence was very marked. (On such occasions four extra *S*—*P*'s were presented before continuing with the regular series, but of course the subject had no way of knowing that she had been the cause of the omission or that extra presentations had been given. If she caused more than one omission, she was reinstructed at the end of the series about keeping the handle on its rest until the turn was actually started.)

Some subjects attributed the disruptive influence to having been tricked in making a turn on the *S*. I suspect a dog, if he were capable, might make a similar complaint about being tricked when the secondary is presented and not followed by the primary. But certainly subjects held no resentment about being tricked later in the experiment, and many did not regard the *S*—*S* as trickery at any time. Furthermore, an *S*—*O* is just as disruptive as an *S*—*S* and does not involve the same degree of trickery, if one wishes to speak of trickery as a possible explanation.

D. Differentiation

Table 3 gives results from those presentations which might

TABLE 3
DIFFERENTIATION

Presentation	Dif.	No. Sub.	Day
E—*S*.....	3.3	7/40	7
E—*P*.....	21.7	30/30	3–4
E—*P*.....	4.6	14/20	9
(*E*—*O*)*S*—*P*.....	.8	11/20	3
(*E*—*O*)*S*—*P*.....	2.1	10/20	7
(*E*—*S*)*S*—*P*.....	2.8	24/40	7
(*E*—*O*)*S*—*P*.....	.0	10/19	11

reveal differentiation. The $E-P$ of the third and fourth days shows a markedly slowed reaction time, as it should if differentiation is made and as it should not if the individual is learning a time interval. The results for the $E-P$ of the ninth day should be given little weight, for previous to this time the subjects had been given the E several times in various combinations. Differentiation is further indicated by the small number of subjects who turned on the $E-S$, and most clearly is it indicated by the fact that the $E-O$'s did not show a disruptive influence as did the $S-O$'s.

E. External Inhibition

Table 4 shows the effect of presenting the extra stimulus (bell) simultaneously with the secondary—$ES-P$, one second

TABLE 4

EXTERNAL INHIBITION

Presentation	Dif. 1	No. Sub.	Dif. 2	No. Sub.	Day
$ES-P$	17.9	37/39	.8	18/39	5
$ES-P$	8.5	34/39	.3	20/39	8–9
$ES-P$	8.4	16/19	.4	10/19	12
$ES-P$	13.4	17/19	x	x	11
$S(E-P$	11.7	37/40	1.2	22/40	7–8
$S(E-P$	9.0	17/19	−.2	12/19	12
$E)S-P$	.4	9/20	.1	11/20	11

after the secondary—$S(E-P$, and one second before the secondary—$E)S-P$. Just why the last type of presentation did not result in inhibition is not clear. That the $ES-P$ slowed reaction time as much as the $S(E-P$ would indicate, it seems, that conditioning of the Pavlovian type is being exhibited rather than some form of judgment of time interval. If subjects were making an intellectual judgment of time interval, they should be approximately as ready after an ES as after an S, while the occurrence of an E between the S and P should interfere with their estimation of time. But results show that they are no more nearly ready after an ES than after an $S(E$.

It is to be noted from the table that the introduction of these altered presentations did not have any effect on the immediately following $S-P$ (columns 4 and 5).

F. Disinhibition

The presentations shown in Table 5 were introduced with the thought that they might possibly reveal a disinhibition of the experimental extinction, but it will be noted that they

TABLE 5

DISINHIBITION

Presentation	Dif. 1	No. Sub.	Dif. 2	No. Sub.	Day
$(S-O)ES-S$....	14.5	3/40			4–5
$(S-O)ES-P$....	13.2	35/40	3.9	31/40	6
$(S-S)ES-P$....	7.8	18/20	8.3	16/20	7–8
$(S-O)ES-P$....	7.9	16/19	3.2	16/19	8–9
$3(S-O)ES-P$....	8.5	18/20	3.3	15/20	10–11
$(S-O)E)S-P$....	2.9	11/20	5.0	15/20	10

TABLE 6

MISCELLANEOUS

Presentation	Dif.	No. Sub.	Day
$(O-O)S-P$.....	−1.0	20/40	2
$(O-O)S-P$.....	.2	20/39	8, 10
$5(E-O)E-P$.....	27.1	20/20	3
$5(E-O)E-P$.....	15.6	19/19	11
$9(ES-P)E-P$.....	4.7	11/20	11

TABLE 7

DAILY AVERAGES

Day	Av.	Day	Av.	Day	Av.	Day	Av.
1a	30.0	4a	22.1	7a	20.8	10a	19.6
1b	26.3	4b	22.8	7b	21.0	10b	19.6
2a	24.3	5a	21.2	8a	20.2	11a	18.7
2b	23.0	5b	21.3	8b	19.7	11b	19.7
3a	22.8	6a	21.4	9a	20.1	12a	18.7
3b	23.3	6b	21.4	9b	20.4	12b	19.2

Standard dev. 4th day = 6.05, 10th day = 3.96.

made no such revelation, except possibly in the case of the $(S-S)ES-P$ and the $(S-O)E)S-P$. In both these cases the reaction time on the succeeding $S-P$ (column 4) was slower than on the $ES-P$ or $E)S-P$ (column 2), while in no case in Table 2 was the reaction on the second $S-P$ slower than on the first. In the case of the $(S-O)E)S-P$ the

reaction to the *P* was not slowed as much as in the case of $(S-O)S-P$'s shown in Table 2. It will be worth while to make further tests of an $E)S-P$ introduced after an $S-O$ or an $S-S$, but the experimenter scarcely expected to reveal disinhibition in any of these presentations. The time interval used in this experiment classes the response as a *delayed reflex*, and disinhibition of this class of reflexes shows as a destruction of the delay according to Pavlov. After an $S-S$ or an $S-O$, an *ES* followed immediately by a *P* may be expected to reveal disinhibition. Improved apparatus will make possible such a test.

G. Miscellaneous

The presentations shown in Table 6 were introduced in an exploratory manner and have little significance.

H. Experimenter's Observations and Subjects' Reports

During the intermission of the first day subjects were asked, "What did the effect of the buzzer seem to be?" It had not been mentioned in the instructions for three groups, while the fourth group was told that a buzzer would be sounded three seconds before the appearance of each light. (There were no discoverable differences in performance between this group and the other three.) Most subjects reported that they almost immediately recognized the signal character of the buzzer, but a few reported that it was confusing and that they attempted to ignore it. For them the task became for a time one in discriminative reaction. Their reaction times were slow as compared to those who recognized the signal character of the *S*, and they were much less likely to show conditioning and associated phenomena. Two subjects continued to react in this manner until the fifth day.

After learning to recognize the signal character of the *S*, subjects passed through three observable stages. First they were obviously tense and ready to turn at all times. Next there was a tensing and getting ready *immediately* upon the presentation of the *S*, with a progressive decease in the amount of readiness before the *S*. Finally they waited for some time after the occurrence of the *S* before preparing to

turn, in the final stages showing no sign of tenseness until the actual turn was made. These stages are quite analogous to Pavlov's findings for delayed and trace reflexes, the response in the first stage showing immediately upon presentation of the *S* and gradually becoming more and more delayed until the delay reaches the full period.

During the first stage of continuous tenseness it was not uncommon for subjects to turn when the secondary was presented, but such turns disappeared almost completely after the first five presentations. Occasionally such a turn would show in the second stage of immediate preparation, *i.e.* the subject would over-prepare.

In the final stage, the delayed readiness, subjects would occasionally turn just at the time the light should appear, but the number of such turns were exceedingly few except for $S-O$ presentations and in the case of one subject. This subject began showing such turns on the eighth day and reported that she could not help making them. Her turns of this nature were accurately timed as could be judged from a feature of the apparatus difficult to eliminate. The contact which presented the *P* lasted 1/3 of a second, and if the subject completed a turn before the end of this time, the *P* would again appear. Normally this would not occur for the reaction time plus the time involved in making a turn would require more than 1/3 second. This subject made the last half of her turn rather slowly, requiring about 1/3 to 1/2 second for the complete turn. Only once or twice did her turns, started before the appearance of the light, fail to coincide with the 1/3 second during which the *P* contact was made. The few such turns made by other subjects during the last two or three days were also accurately timed judged in the same manner. It seems safe to regard these as true conditioned delayed responses. At least they contrast sharply with attempts to guess the time for the appearance of the *P*. One subject indulged quite freely in such guesses, so freely that her records for the first and fourth days were completely discarded, and perhaps all her records should have been eliminated. More than half her turns on these two days came before the light appeared, and

these turns were quite inaccurately timed. She showed less evidence of conditioning than any other subject, even the two who continued to make discriminative reactions for several days.

Similar to these turns occurring just barely before the *P* would have been presented are those with reaction times of less than 10/120ths of a second. There were only seventeen such reaction times during the first four days, but from the fifth day onward they appeared more and more frequently, there being 57 during the first half of the twelfth day, or nearly one in ten. They obviously indicate conditioned responses rather than reaction to the *P*.

The experimenter noted that one subject on the third day began nodding her head when the *S* occurred, and that this nodding dropped out on the last part of the sixth day. At the end of the experiment all subjects were asked if at any time they had counted between the *S* and *P*, and this subject and one other were the only ones who replied that they had. These two reported that they had discontinued the counting, finding, so they thought, that they could achieve a faster reaction without counting.

Reports as to the effect of the test presentations were not sought, but were occasionally volunteered, mainly with reference to the paralyzing effect of inhibitory or extinguishing presentations, obviously because of the strangeness of the effect. Reports of change of method were sometimes reported, but usually these changes were apparent to the experimenter before the report was made.

Discussion

Since the experiment up to the present affords a considerable body of evidence to support the hypothesis that the phenomena of conditioning are exhibited by human subjects and by them when the response studied is a voluntary rather than a reflexive act, and since the results with the improved apparatus will not be directly comparable, the experimenter is reporting his results even though he realizes that they are not conclusive and that many lines of attack have not been tried.

The results throughout have been in line with predictions made from his interpretation of conditioned reflex theory and experiment, and he can think of no other set of principles which would have allowed that prediction or which would unify the results that have been obtained.

The improved apparatus will afford more accurate timing in the presentation of stimuli, will permit time intervals not possible with the old apparatus, will present *P* stimuli whose duration is independent of the quickness of the subject's response, and most important of all, will permit irregular intervals between sets of stimuli. A synchronous motor drives a rotor over a set of contacts in a stator which can be rotated manually between sets of stimuli, and by means of this rotation the interval between sets of stimuli can be varied from three to fifteen seconds with an average interval of nine seconds.

(Manuscript received January 14, 1935)

AN EXPERIMENTAL INVESTIGATION OF THE PROBLEM OF STIMULATION DEAFNESS[1]

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I

'Stimulation deafness' is a name which has been given to the phenomenon of decreased auditory sensitivity following exposure to intense tones and noises. It has long been known that such exposure may result in disordered hearing and, as a consequence, experimenters have frequently utilized this method in order to secure data on pathological hearing for comparison with data on normal hearing, with the expectation that light would thus be thrown on auditory theory. Early investigations are said to have shown that histological alterations are produced in the inner ear through such exposure. Since most of these studies were carried out in German otological laboratories and the results published in relatively inaccessible German otological journals, it has seemed worthwhile to the author to prepare a more complete review of this literature (**5**) than could be published in this experimental article.

In recent years, with the improvement in methods for the examination of the sensitivity of animals, investigators have stressed the importance of securing adequate measures of auditory sensitivity before and after exposure to intense stimulation. Such material is necessary not only for the determination of the possibility of hearing loss, but also for the functional interpretation of histological findings. Upton, in 1929 (**7**), reported that he found a loss for a tone of 600 cycles, with no loss for a tone of 1000 cycles, in guinea-pigs which had been exposed for 70 days to a high intensity of a 600-cycle

[1] This study was directed by Professor Walter S. Hunter of Clark University, partly during the author's preparation for the doctorate and partly during the author's tenure of the Porter Fellowship in Physiology.

tone. Horton (**3**, **4**) and Finch and Culler (**2**) have more recently reported that general losses of sensitivity result from exposure to specific tones of various frequencies. The detailed aspects of these and other studies have been critically surveyed in the historical review (**5**).

II

The Problem

The present investigation was begun as an attempt to verify and explain the results reported by Upton. Therefore the problem of the two preliminary experiments was to determine the effect of 70 days of exposure to a 600-cycle tone on the auditory sensitivity of guinea-pigs for tones of 400, 500, 600, 700, and 800 cycles. In the first of these experiments the exposure tone was at an intensity approximately 65 db above the human threshold and in the second the intensity of the exposure tone was approximately 95 db above the human threshold. The narrow range of test frequencies from 400 to 800 cycles was chosen because the results reported by Upton would lead one to expect rather specific loss of sensitivity for the exposure tone. It became evident during these preliminary experiments that tests must be made over a wider range of frequencies. Therefore a third experiment was carried out in which tests were made with frequencies of 200, 600, 1000, 1500, 2000, 2500, 3000, 4000, 6000, and 8000 cycles per second. In this case a 2400-cycle Edelmann whistle was used as the exposure tone. Earlier German experiments (**5**) had indicated that this exposure tone should be effective in producing histological damage in the auditory receptor.

III

Apparatus and General Method

The apparatus consisted of (1) a training-testing apparatus and (2) an exposure apparatus. The training-testing apparatus consisted of a sound source, a sound-reducing chamber, an animal holder, a device for administering electric shocks, and suitable recording apparatus. A General Radio 613-B Beat Frequency Oscillator and a Stromberg-Carlson 5-A Loud Speaker were used in the preliminary experiments. A dynamic loud speaker was used for the higher frequencies in the last experiment.

A 6000-ohm L-Section attenuation box was used to vary intensity. The sound-reducing chamber was a double box of celotex, which had a layer of five inches of sawdust between the inner and outer walls. Its inside dimensions were 2′ by 2′ by 3′. A Porter inductorium, with 1½ volts in the primary and the secondary set at 3 cm, provided current for shocking. The current was applied by means of wire electrodes wrapped around the hind legs of the animals. The legs were dampened to improve electrical conductivity and thus make it unnecessary to remove the hair. A box with wooden sides and wire-mesh top and ends, just large enough to contain the animal, was used to hold him at a distance of 12 ins. from the loud speaker. The recording apparatus consisted of a kymograph, signal markers, a Jacquet timer, and a pneumograph-tambour arrangement for recording breathing. A small rubber balloon was placed between the animal and a metal belt, which extended from his fore legs to his hind legs. The belt was fastened securely by means of two straps, one of which was placed back of the shoulders and the other in front of the hips. A rubber tube led to a tambour, the diaphragm of which was made from a surgical finger stall. A long stylus gave about a 15-fold magnification of the diaphragm deflections. This simple device, inflated by means of a bulb and valve, yielded a degree of sensitivity such that ordinary breathing of the animal gave an amplitude of kymograph record of about one centimeter.

Near the threshold of sensitivity it was necessary to be certain that no 'click' was produced in the loud speaker at the onset of the tone. Such a click was avoided by a method similar to that described by Stevens (**6**). The fact that limens were obtained is the best evidence that the animal was not responding to cues introduced by the experimenter or by the manipulation of the recording apparatus. 'Control' series in which the experimenter went through his usual procedure without presenting a tone also showed that no extraneous cues were effective.

The apparatus used in the exposure of the animals in the preliminary experiments consisted of a General Radio 213 Audio-Oscillator (tuning-fork microphone-button type), which delivered a frequency of about 600 cycles per second, a 6-volt storage battery, a loud speaker, and wire living cages. This apparatus was placed in a sound-reducing room, the inner dimensions of which were 6′ (height) by 9′ 9″ by 9′ 9″. This exposure room was ventilated once or twice a day by opening the doors and driving out the air with an electric fan. (The exposure apparatus used in the major experiment will be described below.)

The testing procedure was as follows: An animal was brought into the experimental room, fastened securely into the pneumograph belt with electrodes wrapped around his hind legs, and placed in the wire box within the sound-reducing box. After a very short time his breathing became quite regular, and his training or testing was begun. All animals were first conditioned to the highest available intensity of the 600-cycle tone. This could usually be completed during the first two experimental periods of about 30 minutes each. A sample record showing the conditioned response is presented in Fig. 1.

The method of conditioning employed, important in that it seems to have yielded results in fewer trials than have been necessary when other methods have been used, was as follows: (1) Conditioning stimuli preceded unconditioned stimuli by short intervals of time (one to four seconds). (2) Conditioning stimuli and unconditioned stimuli were terminated simultaneously. (3) The length of the interval between the onset of the tone and the beginning of the shock was varied so as to avoid the establishment of a delayed reflex. (4) The length of the interval between successive stimulus pairs was varied so as to avoid the establishment of a reflex rhythm. (5) Conditioning

stimuli were *invariably* followed by unconditioned stimuli so as to avoid any possible extinction of the reflex which might result from lack of reinforcement. Due to the brief latent time of the response to tone, this response occurs prior to the response to shock and hence can be distinguished from it (see Fig. 1). (6) Ten to twenty presentations per day were given.

Ten to twenty presentations of tone and shock were usually sufficient to establish a fairly strong and regularly recurring respiratory gasp to the tone. In some animals

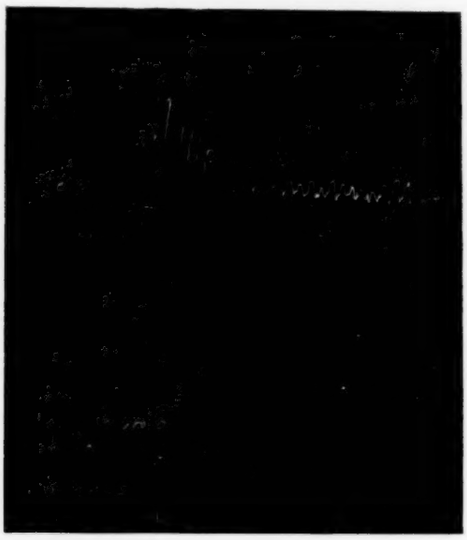

FIG. 1. The conditioned response.

the 'startle' reflex, which is usually elicited during the first few presentations of a new stimulus, continued to be given throughout successive trials. In other animals no startle reflex was evident during the first 8 or 10 trials. In other animals the startle reflex diminished in strength or disappeared after the first four or five trials and reappeared after the 15th or 20th trial. For the purpose of the present investigation any respiratory change, learned or unlearned during the progress of the experiment, which occurred regularly following auditory stimulation was regarded as a response to sound. It seems probable, however, that the reflex used in this study was a reinforced startle reflex rather than a new conditioned response.

After the response began to follow with great regularity the presentation of the maximal intensity of the 600-cycle tone, progressively weaker intensities of the same tone were presented until no response occurred. An intensity series consisted of tones produced with 0, 6, 12, 18, 24, 30, 36, 42, 48, 54, or 60 decibels of attenuation from a constant voltage level. Preliminary intensity series using all five frequencies were given to each animal before actual limen determinations were begun. In each of these series 12 to 20 tone-shock pairs were presented, so that by the time the limen determinations began each animal had been 'overconditioned' to the extent of 60 to 100 trials and had become accustomed to respond to series of gradually decreasing intensities.

After this preliminary training, limen determinations were made with each animal for each of the tones. The method, chosen on account of the fact that it seemed to give fairly consistent limens in a minimum of time, was as follows: Only descending series were used. A high intensity, maximal or almost maximal for the apparatus, was presented for a number of times. When the respiratory change following its

onset became of short latency and great amplitude (as in Fig. 1), the amount of attenuation in the loud-speaker circuit was increased in steps of six decibels each. The resulting lower intensity was only presented once or twice if the animal clearly responded to it. If he did not respond during the first two or three presentations (this was seldom the case until fairly low intensities were reached), the tone was presented about ten times in succession. If the animal responded in 50 percent of the cases in which a given intensity was presented, an intensity six decibels lower was then given. This procedure was continued with decreasing intensities until that intensity was reached at which the 50 percent criterion was not met. That intensity was regarded as subliminal.

IV

Preliminary Experiments

1. *First Experiment*

a. Specific Problem and Method.—Nine adult guinea-pigs were first thoroughly conditioned to tones of 600, 700, 500, 800, and 400 cycles, in this order. After several preliminary intensity series a single determination was made of the threshold of each animal for each of these tones. Then the animals were placed in the exposure room and exposed continuously for 70 days to a 600-cycle tone of an intensity approximately 65 decibels above threshold. Three of them were retested at the end of 30 and 40 days of exposure. All of the animals were removed from the exposure room on the 70th day, and their thresholds were redetermined during the following week. The order of redetermination was 600, 700, 500, 800, and 400. Later redeterminations of the threshold for the exposure tone were made on three of the animals during the following three weeks.

b. Results.—Three of the nine animals showed no decrease in sensitivity at the end of the exposure. Three others showed small gains and losses which were not regarded as significant. The other three animals showed a loss of considerable magnitude (24 to 30 db) for the exposure tone and smaller losses for neighboring tones, when tested at the end of the exposure period. Two of these last three animals were found to possess normal sensitivity one or two weeks after removal from the exposure room. The one animal which had not recovered at the end of three weeks was examined electrophysiologically by Dr. Hallowell Davis of the Harvard Medical School and was found to have a normally functioning peripheral auditory

receptor. It was apparent that failure to respond to a tone after exposure may not be indicative of any damage or loss of function of the peripheral auditory receptor. Accordingly, the loss of sensitivity, where found, seems to have been due to a lack of complete reconditioning rather than to a peripheral change during the exposure.

2. *Second Experiment*

a. Problem and Method.—This experiment was planned to test the effect of exposure to a higher intensity of the frequency used in the preceding experiment. Five adult guinea-pigs were used as subjects. The apparatus used in training and testing the animals was the same as in the preceding experiment. The exposure apparatus was the same as that in the preceding experiment except for the fact that one stage of amplification was introduced between the output of the 213 Oscillator and the loud speaker.

The general procedure was essentially the same as in the preceding experiment, with the difference that thresholds were computed from a greater number of tests and the redeterminations of the thresholds for each of the tones after exposure were made during short daily periods of removal of each animal from the exposure room between the 65th and the 75th days. Between separate determinations the animals were kept in the exposure room, so that the thresholds obtained are comparable one to another in that the same amount of recovery, if any, must have occurred prior to each determination.

Another change in the method of redetermination of thresholds was made in order to make certain that the thresholds obtained for all tones would be comparable. A preliminary intensity series with each frequency was presented to each animal before the first redetermination was begun. In each of these five series, 15 to 20 tone-shock pairs were presented. Thus a total of 75 to 100 reconditioning trials were given before the redetermination of thresholds was begun. Two series of redeterminations were made.

b. Results.—Thresholds of the five animals for frequencies

400, 500, 600, 700, and 800 cycles, before and after exposure, are given in Table 1. It is apparent from the table that there is usually a considerable loss in sensitivity for all five fre-

TABLE 1

SHOWING LIMENS OF INDIVIDUAL ANIMALS BEFORE AND AFTER EXPOSURE TO A 600-CYCLE TONE 95 DB ABOVE HUMAN THRESHOLD

Animal	Frequency	Thresholds		
		Before Exposure	After Exposure	
			Series 1	Series 2
50	400	6	18	18
	500	10	22	22
	600	22	28	28
	700	4	16	16
	800	8	32	26
51	400	0	18	24
	500	−2	16	22
	600	4	34	28
	700	4	16	16
	800	8	26	32
53	400	60	66	66
	500	64	64	70
	600	64	70	70
	700	58	64	46
	800	56	62	62
54	400	0	18	18
	500	16	22	22
	600	4	28	28
	700	10	10	16
	800	2	32	14
55	400	−6	18	12
	500	−2	22	16
	600	4	28	16
	700	4	22	4
	800	8	20	20

The limens are given in terms of number of decibels of attenuation by which they failed to reach the average human threshold. The larger the amount of attenuation, the less sensitive the animal.

quencies following the exposure. It is equally apparent that there is little reliable evidence for a specific or maximal loss for the exposure tone as compared with the losses for the neighboring tones.

Animal 53 was quite insensitive to sound, even before the

exposure, as may be seen from Table 1. He was exposed with the other animals, although it was believed that his sound-conducting mechanism was probably defective. This animal suffered comparatively little loss in sensitivity during the exposure. Later examination of his ears revealed the fact that both middle ears were filled with pus.

Another guinea-pig, whose audiogram is not presented, was found in pre-exposure tests to possess a level of sensitivity comparable to that of animal 53. In order to determine whether the high threshold was due to anatomical abnormality or to incomplete conditioning, the animal was given a dose of strychnine (which, unfortunately, proved to be lethal after one hour). Threshold determinations were made before and during the convulsive seizures which ended in the death of the animal. Although the amplitude of the response to weak tones increased considerably, the thresholds were not lowered at any time and appeared to be about six decibels higher during the later determinations.

Certain of the animals of this group were examined by Dr. Davis and Dr. Lurie. Their examinations usually corroborated the results reported here for conditioned reflex tests in that they showed a small general loss of sensitivity over the range from 400 to 800 cycles (see 1, p. 258).

3. *Summary of Results from Preliminary Experiments*

Animals exposed for 70 days to a 600-cycle tone of moderately high intensity (65 db above the human threshold) may show large losses for the exposure tone and smaller losses for tones of 400, 500, 700, and 800 cycles, if thresholds are determined immediately after the termination of the exposure. Such losses usually disappear with complete reconditioning and are probably not indicative of any break-down of the peripheral receptive mechanism. Electrophysiological and histological examinations in these cases failed to reveal any lesions in the end-organ. Exposure to very high intensities (95 db above the human threshold) of a 600-cycle tone appears to result in a general loss of sensitivity of about 18 db over the range of frequencies from 400 to 800 cycles per second.

Histological and electrophysiological examinations have been made of the ears of some of the animals of this group and the results of those examinations have usually corroborated the finding of a small general loss of sensitivity over the range from 400 to 800 cycles.

V

Major Experiment

1. *Problem.*—A survey of the results of previous experiments (**5**) had indicated that histological damages in the cochleae of guinea-pigs might be produced more easily with high tones than with low tones. Therefore it was decided to expose normal guinea-pigs to an intense tone from an Edelmann whistle of 2400 cycles. The effect of such exposure on the sensitivity of these guinea-pigs for tones of 200, 600, 1000, 1500, 2000, 2500, 3000, 4000, 6000, and 8000 cycles was determined by conditioned reflex tests before and after their exposure.

2. *Method and Apparatus.*—Three guinea-pigs were selected from nine conditioned animals on the basis of ease of conditioning, lack of irregularities in the audiogram, and reliability of pre-exposure limens. The audiograms of these three guinea-pigs were similar to one another and to the human audiogram. The method of limen determinations was similar to that used in the preceding preliminary experiments except that the intensity was varied in steps of 2 db instead of 6 db. Three independent determinations of the limen were made for each frequency for each animal. An average of these three determinations was taken as the pre-exposure limen for each animal. The average of the deviations for each frequency for each animal ranged from .67 db to 4.67 db. Extreme deviations were 6.67 db for animal No. 1, 6.33 db for animal No. 2, and 4.00 db for animal No. 3. The average deviation for all pre-exposure thresholds from the values given in the audiograms as the '0 hearing-loss' was about 3 db. These figures show that the pre-exposure thresholds of these three guinea-pigs were sufficiently consistent that a hearing loss of more than 10 db might with reasonable certainty be held to be significant.

All pre- and post-exposure limen determinations were made with the animal enclosed in the sound-reducing box described above and, as an additional precaution, these determinations were made in the evening when the building was quiet.

At the conclusion of the threshold determinations the animals were placed in a wire living cage similar to that used in the previous experiments. They were exposed for about 12 hours per day for a period of about six weeks to an intense tone from a d_4 Edelmann whistle. The frequency of the whistle was found to be 2400 cycles per second and its intensity about 95 db above the human threshold. The whistle was fastened to one side wall of the cage and its opening was on a level with and directed toward the ears of the animals. Pressure for blowing it was obtained from a water pump. Tests were made during the last three weeks of the exposure period. Two series of tests were made for animal No. 1 and three series for animals No. 2 and No. 3. The reliability of the averages of these determinations was about the same as in the pre-exposure tests except for the smaller number of tests. Deviations from the average of the three series of post-exposure limen determinations (two series for animal No. 1) were never greater than 4 db and averaged about 3 db. It is believed that the reliability of the pre- and post-exposure limen determinations was sufficiently high to make a hearing loss of 10 db significant.

These animals were taken to the Harvard Medical School and examined by Dr. Davis and Dr. Lurie as in the previous experiments. The results of their examination will be published later.

3. *Results.*—Figure 2 shows the hearing loss for each animal for each of the frequencies 200, 600, 1000, 1500, 2000, 2500, 3000, 4000, 6000, and 8000. It may readily be seen that there is no specific loss for the exposure frequency. The greatest losses are consistently found at 2000 cycles. Losses tend to be of less magnitude for frequencies above 4000 and indeed only one of the three animals may be said to have a significant loss for any frequency above 3000 cycles. The loss

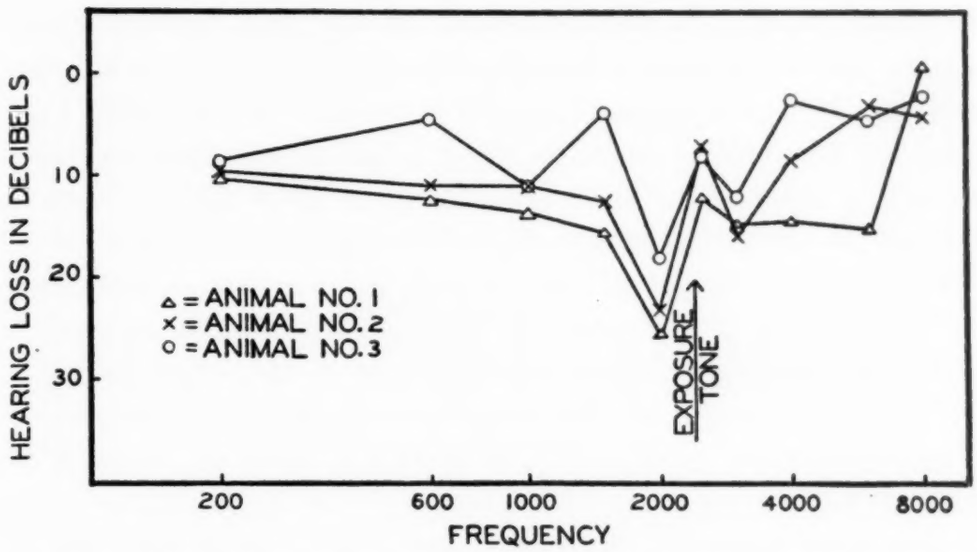

FIG. 2. Graph showing hearing loss in decibels for each of the three animals which had been exposed to the 2400-cycle whistle. Each animal's pre-exposure limen for the tones used is represented by the zero level of hearing loss. The curves thus show directly departure from each animal's pre-exposure limen. The abscissa values of the graphs are 200, 600, 1000, 1500, 2000, 2500, 3000, 4000, 6000, and 8000 cycles.

is a wide-spread one, as has previously been reported by Horton (**3**, **4**) and Finch and Culler (**2**). It is an interesting fact that the losses were fairly consistent from animal to animal. This may have been a consequence of the similarity of their audiograms and, presumably, of their receptive mechanisms, prior to the exposure.

VI

DISCUSSION

The preliminary experiments have apparently provided an explanation of the results reported by Upton. He was unable to secure responses from guinea-pigs to a low intensity of a 600-cycle tone after they had been exposed for 70 days to a high intensity of that tone. Complete reconditioning to a higher intensity and subsequent tests with decreasing intensities might have revealed small or insignificant losses of sensitivity for the exposure tone.

The results of my experiment with a 2400-cycle exposure tone seem to indicate that the consequent loss of sensitivity may be greatest for frequencies other than the exposure

frequency itself. It appears that the maximal loss produced by this exposure tone is for the frequency of 2000 cycles per second. It is not easy to find an explanation for this fact. Possibly the basilar area in the region of greatest auditory sensitivity (which includes sensitivity to 2000 cycles) is more susceptible to damage by injurious agents than are other areas. The wide-spread loss for neighboring frequencies may have been due to a change in the conducting mechanism of the middle ear rather than to a damage in the inner ear.

From the results of this experiment and from the experiments of Horton (**3**, **4**) and Finch and Culler (**2**), it must be concluded that the locus of histological lesion produced by an intense tone cannot be directly correlated with the 'place' which serves normally as the receptive area for that tone. This does not mean, however, that these results provide evidence against the place theory of audition. On the contrary, electrophysiological and histological examinations of the ears of similarly exposed animals (**1**) have been found to offer support for the place or resonance theory. We must conclude, however, that injuries produced by very intense tones are wide-spread and are not localized in the region which is stimulated by the exposure tone at near-threshold intensities.

VII

Summary

Some guinea-pigs which had been exposed to a 600-cycle tone of moderately high intensity failed to respond to low intensities of this tone immediately after the exposure. Reconditioning of these animals to these low intensities was possible in two out of three cases. Guinea-pigs which had been exposed to a very high intensity of this 600-cycle tone showed a general loss of sensitivity of about 18 db over the range from 400 to 800 cycles.

Guinea-pigs which had been exposed to a very high intensity of a 2400-cycle Edelmann whistle were found to have suffered losses of sensitivity from their pre-exposure thresholds. These losses were wide-spread and were maximal for a frequency of 2000 cycles. It is concluded that these results

do not provide evidence against the place theory of audition but that they do provide an argument against the correlation of the lesion produced by an intense tone with the localization of the receptive area for normal intensities of that tone.

(Manuscript received December 15, 1935)

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CERTAIN SOMATIC ACTIVITIES IN RELATION TO SUCCESSFUL AND UNSUCCESSFUL PROBLEM SOLVING

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PART III

Relation of Action Potentials and Muscular Movements and Tensions to Successful and Unsuccessful Problem Solving [1]

This investigation has to do with the relationship between involuntary muscle contractions, tensions and action potentials during successful and unsuccessful problem solving. Bills [1] has pointed out that subjects while squeezing pneumatic bulbs did more effective mental work than while they were not pressing on the bulbs. Our investigation is just the converse of that of Bills because we are attempting to determine what happens with regard to certain somatic activities during mental work. Others have shown that when the subjects are striving hard to do their work there is increased activity of those organs which are indispensable to the accomplishment of the task.[2] The present problem has to do with activity of those organs whose function does not seem to be indispensable in the performing of the work in hand.

A tambour was attached to a chair arm and a cork plaque was fastened to the tambour. Across the top of the plaque was a wooden bar four inches long. From this tambour a rubber tube led to another tambour which wrote upon a smoked drum. The tambour arrangement was calibrated empirically and it was found that a change in pressure of forty grams upon the subject's tambour effected a change of

[1] For discussion of other somatic activities, see two previous issues of this journal.

[2] For more extended summary of literature, see Part I.

one millimeter in the height of the tambour point writing upon the drum. A Harvard timer in series with a signal marker indicated the time in one-second intervals. Two telegraph keys each in series with a signal marker were employed as signals by E. Action potentials were measured by an amplifier and electron oscillograph set-up to be described in a publication by R. C. Davis. Records of action potentials were secured by means of photographic contact prints of the path of the cathode ray spot. S was seated on a chair in a cage which was constructed to keep out any effect of the electric fields of the building. This cage was 3′ wide, 4′6″ long and 5′6″ high. It was constructed of galvanized iron to a height of 4′6″ and the top was made of screen wire mounted upon a wooden frame. Besides serving to keep out electrical interference, this cage also served to separate S from E and the recording apparatus. S was provided with plenty of light and ventilation.

The fingers of the subject's right hand were placed on top of the bar on the tambour and his thumb was hooked underneath, thus effecting a grasping position. The chair arm was adjusted in such a manner as to take strain from the subject's arm. The subject was told to hold his arm in this position and that the tambour arrangement would be used 'as a signal' after a few minutes. He was told that he would be instructed as to when to signal after the experiment started.

The active electrode was attached to the upper side of the subject's right forearm and the right foot was placed in a bath of physiological saline solution which served as the inactive electrode. The purpose was not to localize the contractions but to determine whether or not there is a difference in the amount of contractions during the mental work of successful and unsuccessful subjects as compared with their respective resting conditions. The cardiogram which is easily distinguished from other phenomena (see Fig. 1) is eliminated from the computations.

One experimenter operated the kymograph signal markers, while a second experimenter [3] operated the oscillograph. The

[3] R. C. Davis under whose direction this research was conducted served as the second experimenter.

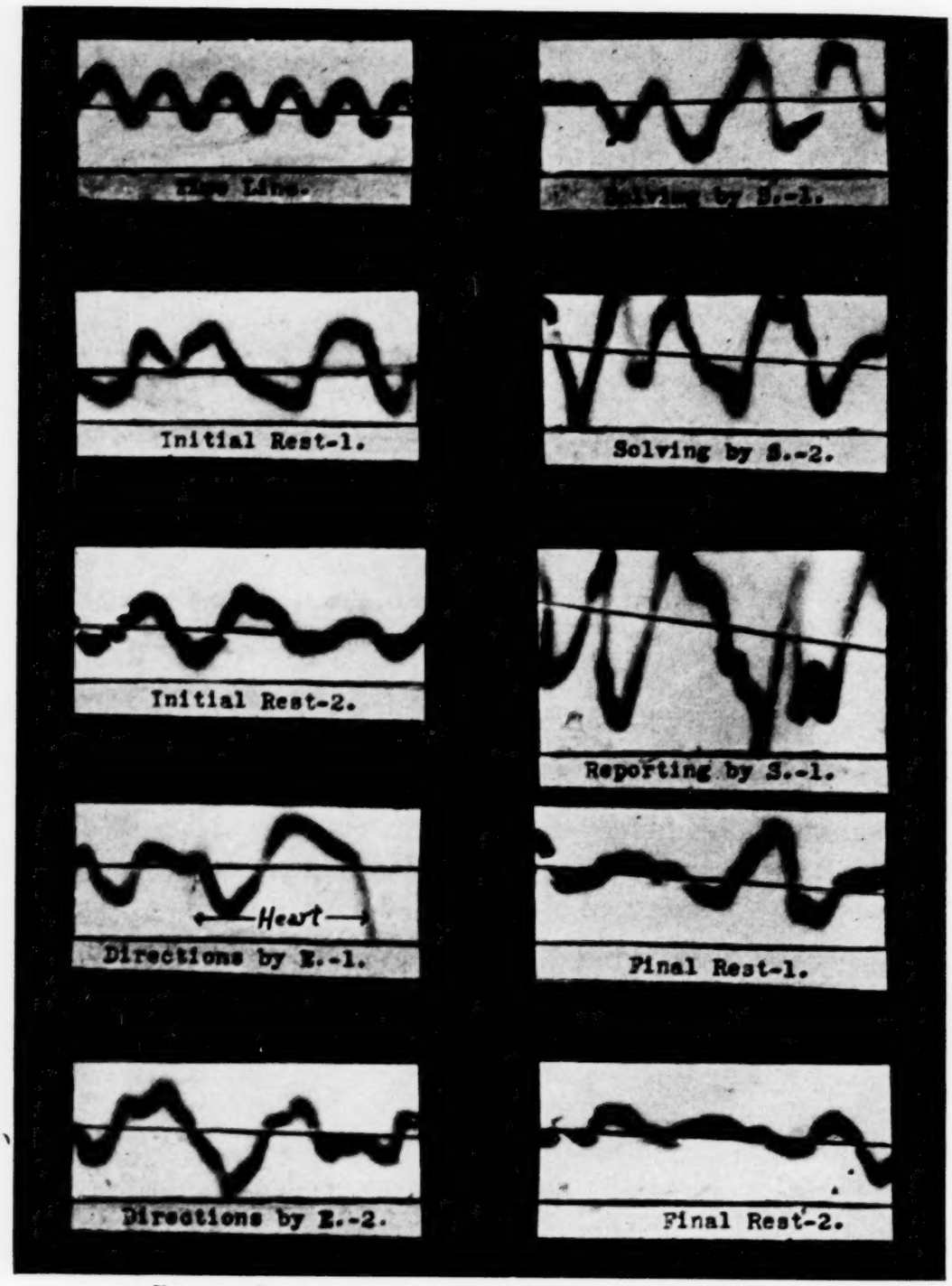

FIG. 1. Record of action potentials by a successful subject.

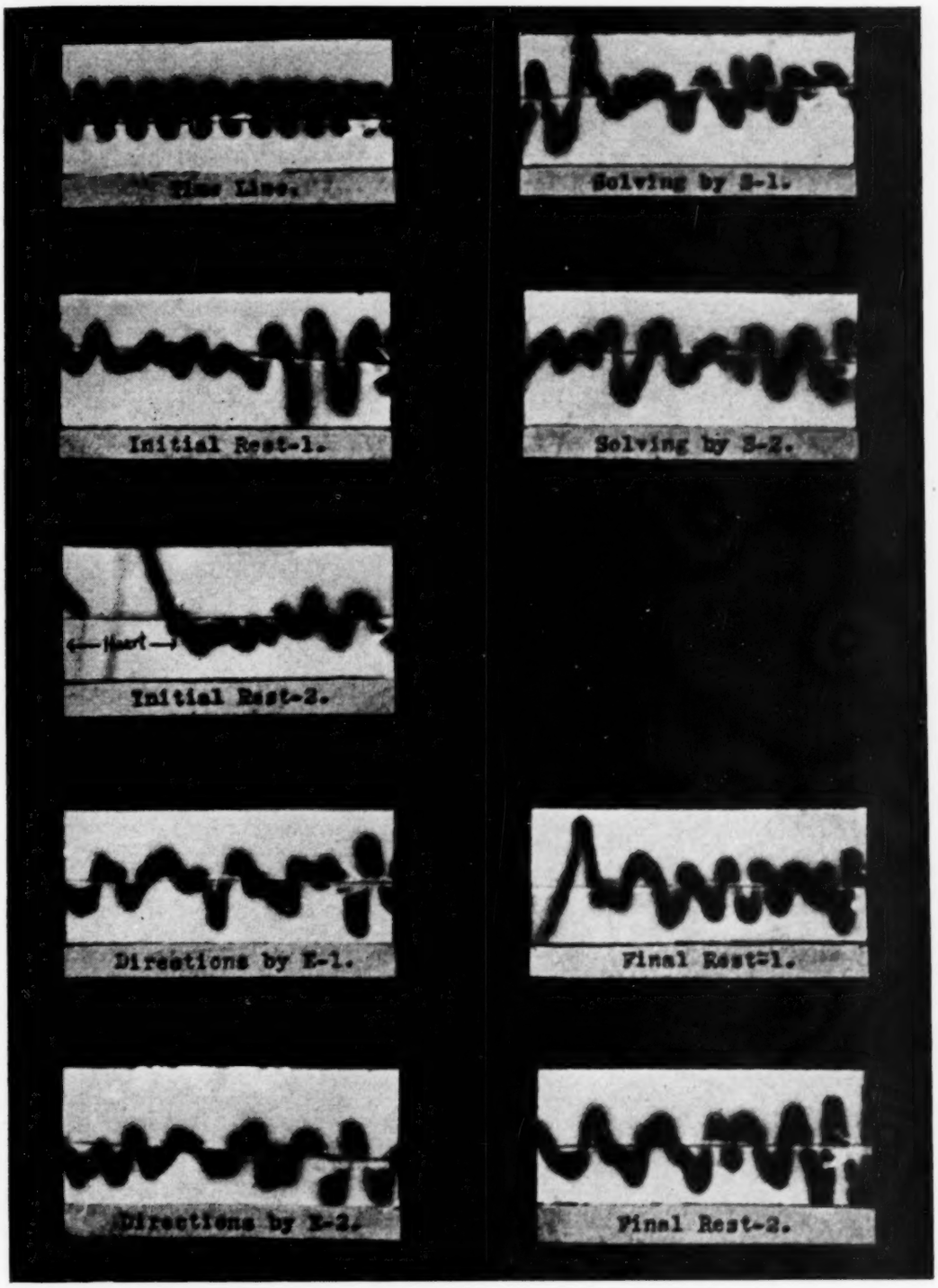

FIG. 2. Record of action potentials by an unsuccessful subject.

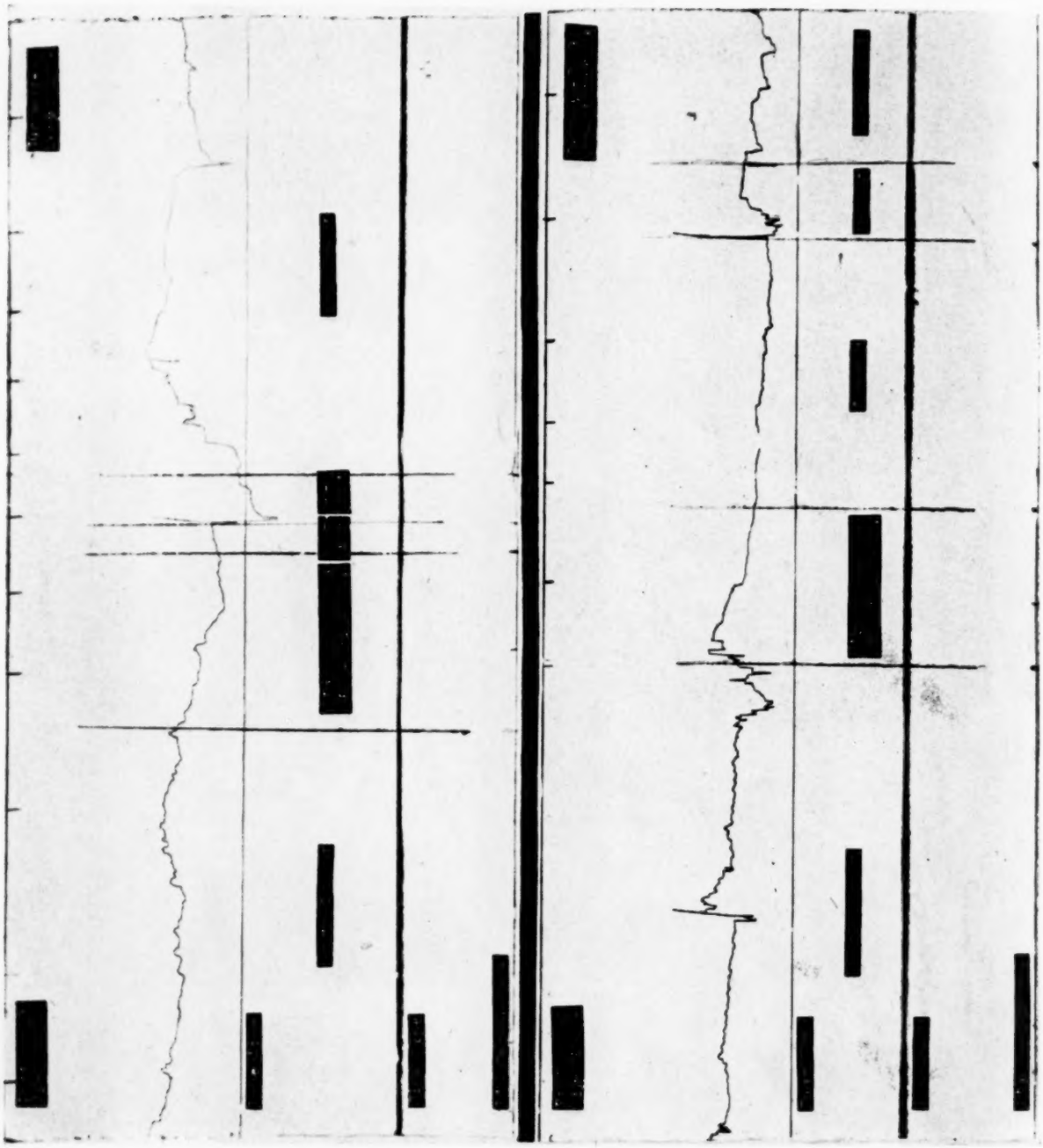

FIG. 3. Sample kymograph records for successful subjects.

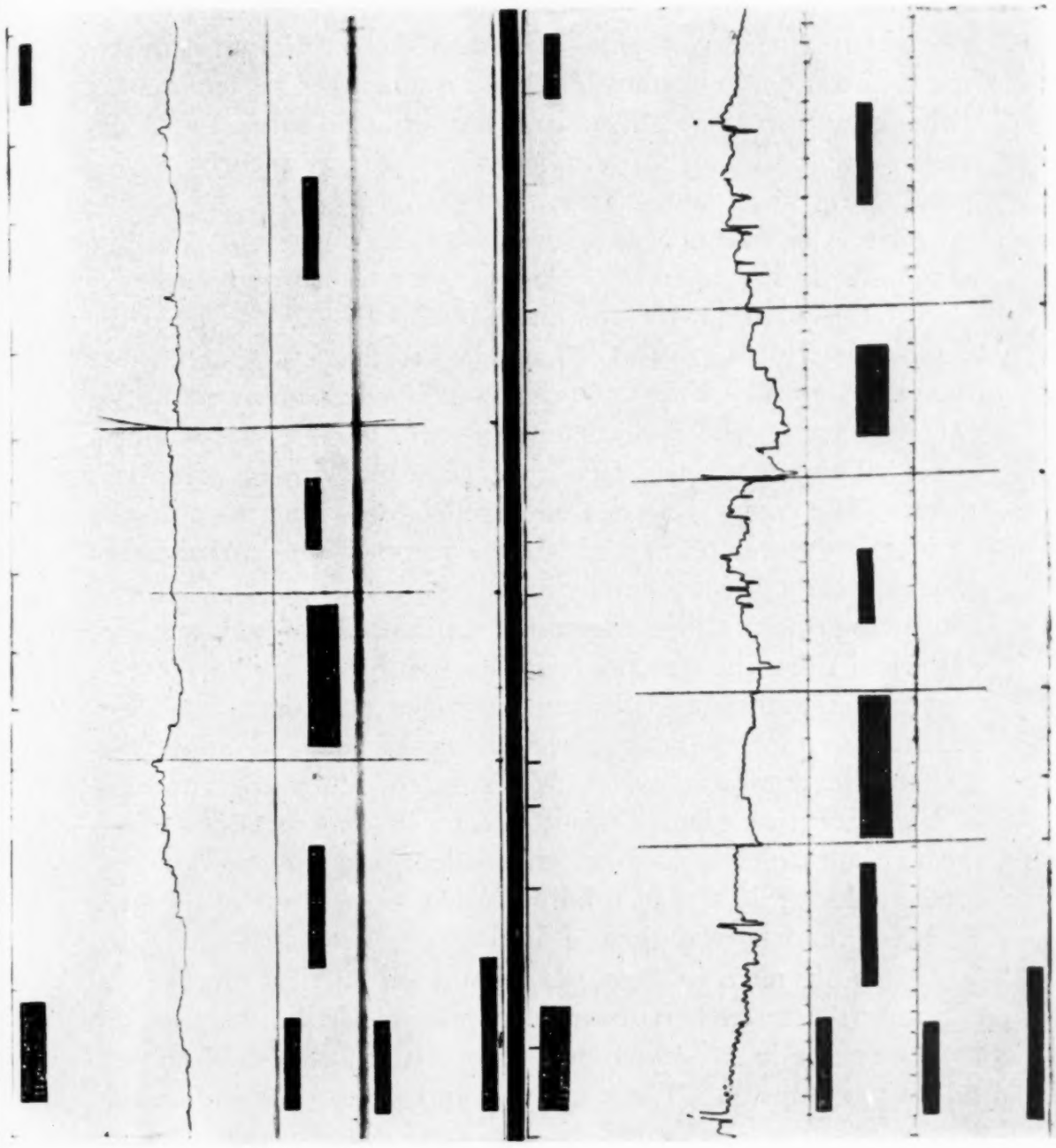

FIG. 4. Sample kymograph records for two unsuccessful subjects.

FIG. 3. Sample kymograph records for successful subjects.

problem given the subject was the second water dipping problem found at the superior adult level of the Binet Test. Records were taken during a rest period, a reading, a solving, a reporting, and a final rest period. If S reached a solution or gave up, he made a signal by means of the tambour arrangement but in case no such signal was made after approximately three minutes, S was told to quit bothering to solve it and was assured that the purpose was merely to secure records during mental rest and mental effort.

After the sitting was over S was disconnected from the oscillograph and a sixty-cycle current was thrown into the circuit. A photograph was made of the flash produced while this regularly alternating current was affecting the path of the cathode ray. This photograph gave a basis for computing the velocity of the spot in crossing the top of the vacuum tube. This record was used as a 'time line' in the computations. The sixty-cycle current used is one generated at the University power plant and is not equipped with a stabilizer. It was assumed that the current did not vary enough during the sitting of one subject to affect results. However, such an empirical time line was made for each subject.

On the photographs taken from the oscillograph all deflections of more than 3 mm were measured and added together and computations were made to determine the sum of the deflections which would occur in one second. Then the averages of the sums of the deflections per second were computed for initial rest, reading of directions, time of solving, giving of report (if any), and final rest.

On the kymograph records all sudden vertical changes of 1/2 mm or more either up or down were added and computations were made to determine the total amount of such movements per minute. The computations give some indication of the relative steadiness of S's hand during the various situations.

The pressure level was also determined. At the outset the tambour point was arbitrarily set at 2 cm above the base line and as S varied his grip pressure the tambour point would rise or fall. In order to measure these changes in level,

TABLE I

SUM OF THE ACTION POTENTIAL DEFLECTIONS PER SECOND MADE BY SUCCESSFUL SUBJECTS DURING EACH OF THE ACTIVITIES SPECIFIED

	Initial Rest	Directions by E	Solving by S	Report by S	Final Rest
N	16	16	15*	11*	15
Ave	393†	429	578	640	469
r with first rest		+.84	+.86	+.99	+.80
S.D.$_{r_1}$		±.102	±.092	±.007	±.127
r with last rest		+.86	+.72	+.96	
S.D.$_{r_2}$		±.093	±.169	±.028	
Difference / S.D. (Diff.) vs. first rest‡		.94	3.7	3.9	1.8
Difference / S.D. (Diff.) vs. last rest§		.83	1.5	3.0	

* During some of the periods no photograph was secured. This accounts for the different N's.

† Computations were made to determine whether or not the average during the initial rest would be different by using readings taken from 15 or 11 subjects, respectively, and it was found that the average for 15 subjects was 398 and for 11 subjects it was 399. Thus the readings would not be affected by using fewer cases.

‡ There were more action potentials during successful problem solving than during a previous period of rest. There tended to be more potentials during listening to directions and during final rest than during initial rest.

§ There were more action potentials during the reporting of the problem than during final rest and there tended to be more of such potentials during listening to directions and during solving than during final rest.

TABLE II

SUM OF THE ACTION POTENTIAL DEFLECTIONS PER SECOND MADE BY FALLING SUBJECTS DURING EACH OF THE PERIODS SPECIFIED

	Initial Rest	Directions by E	Solving by S	Report* by S	Final Rest
N	12	11†	12		12
Average‡	332	349	345		405
r vs. first rest		+.70	+.72		
S.D.$_{r_1}$		±.209	±.193		
r vs. final rest		+.83	+.78		
S.D.$_{r_2}$		±.127	±.155		
Difference / S.D. (Diff.) vs. first rest§		.22	.40		
Difference / S.D. (Diff.) vs. final rest‖		2.6	2.2		

* There were too few cases of report to justify computations for this period.

† During the reading of directions no record was secured for one subject.

‡ The averages, if only 11 cases had been considered in all the periods, would have been: First rest, 330; Dir., 349; Solv., 345; final rest, 400. Thus, it is evident that the dropping of the one subject during the reading of directions does not materially affect the data here presented.

§ There is so little increase in action potential during directions and solving as compared with initial rest as to be considered insignificant.

‖ Failing subjects tend to increase the action potentials during final rest as compared with potentials during listening to directions and solving.

stations were laid off on the base line at each 1/2 cm. These stations corresponded to ten seconds in time. After these stations were thus laid off the vertical distances from the base line to the 'activity line' were measured and computations were made of the average level maintained during initial rest, giving of directions, solving, reporting, and final rest.

The following group of tables, Nos. III and IV, has to do with the vertical movements of the hand during the various activities.

TABLE III

SUM OF VERTICAL MOVEMENTS PER MINUTE MADE ON THE KYMOGRAPH RECORD BY SUCCESSFUL SUBJECTS DURING EACH OF THE PERIODS SPECIFIED

	First Rest	Directions by E	Solving by S	Report by S	Final Rest
Number subjects	16	16	16	16	16
Average	31.3	29.3	21.0	44.3	33.9
r with first rest		+.47	+.39	+.39	
S.D.$_{r_1}$		±.282	±.296	±.296	
r with second rest		+.40	+.20	+.49	
S.D.$_{r_2}$		±.296	±.338	±.268	
Difference / S.D. (Diff.) vs. first rest		.3	1.5*	1.5†	
Difference / S.D. (Diff.) vs. second rest		.6	1.7*	1.3†	

* There tends to be less vertical action of the hand during solving than during either initial or final rest.

† There tends to be more vertical action of the hand during reporting than during either initial or final rest.

TABLE IV

SUM OF THE VERTICAL MOVEMENTS PER MINUTE MADE ON THE KYMOGRAPH RECORD BY FAILING SUBJECTS DURING EACH OF THE PERIODS SPECIFIED

	First Rest	Directions by E	Solving by S	Report by S	Final Rest
Number subjects	12	12	12		12
Average movements	16.5	11.7	15.8		22.5
r with first rest		+.40	+.50		
S.D.$_{r_1}$		±.338	±.302		
r with final rest		+.74	+.68		
S.D.$_{r_2}$		±.183	±.217		
Difference / S.D. (Diff.) vs. first rest*		2.0	.24		
Difference / S.D. (Diff.) vs. final rest†		2.0	1.5		

* There is a slight tendency for unsuccessful people to be less active during the reading of the problem than during the preceding rest, but this difference is not present during solution.

† There is a slight tendency for unsuccessful subjects to be more active muscularly during a period of rest after the problem solving than during the attempted work.

TABLE V

AVERAGE PRESSURE REGISTERED BY SUCCESSFUL SUBJECTS DURING THE PERIODS INDICATED

	Initial Rest	Directions by E	Solving by S	Report by S	Final Rest
Number subjects	16	16	16	16	16
Average pressure	20.3	17.4	14.8	15.4	16.6
r with first rest		+.89	+.72	+.61	
S.D.$_{r_1}$		±.07	±.169	±.226	
r with final rest		+.79	+.91	+.78	
S.D.$_{r_2}$		±.141	±.056	±.141	
Difference / S.D. (Diff.) vs. first rest		2.4*	4.2*	2.2*	
Difference / S.D. (Diff.) vs. final rest		.7	2.1†	.9	

* Subjects doing successful problem solving tend to exert less grip pressure during the time they are listening to the directions and during their report. They register decidedly less pressure during solving than during initial rest.

† There is a tendency for successful subjects to register less grip pressure during problem solving than during a subsequent period of mental rest.

TABLE VI

AVERAGE PRESSURE REGISTERED BY FAILING SUBJECTS DURING THE PERIODS INDICATED

	Initial Rest	Directions by E	Solving by S	Report by S	Final Rest
Number subjects	12	12	12		12
Average height	18.3	16.3	15.7		17.1
r with first rest		+.85	+.58		
S.D.$_{r_1}$		±.116	±.259		
r with final rest		+.73	+.71		
S.D.$_{r_2}$		±.189	±.172		
Difference / S.D. (Diff.) vs. first rest		1.0	1.7*		
Difference / S.D. (Diff.) vs. final rest		.5	.93		

* There is a slight tendency for failing subjects to exert less grip pressure during attempted solving than during a preceding period of mental rest.

In this research there was more difficulty in ascertaining whether the failing subjects gave up or persevered, so the data gathered deal primarily with differences between successes and failures and between the performances during the rest periods and the activity periods for the respective groups.

Inspection of Table I reveals that successful subjects exhibit more action potentials during problem solving and reporting of solution than during rest. It will be noted that the tensions of successful subjects have a tendency to subside

during a rest period following the reporting period. Failing subjects, on the other hand (see Table II), exhibit very little more action potentials during problem solving than during a preceding period of no mental work. These action potentials have a tendency to increase during a period of rest after the work instead of subsiding as in the case of successful subjects. There is very little difference in the action potentials (see Fig. 5) for successful and unsuccessful subjects during the

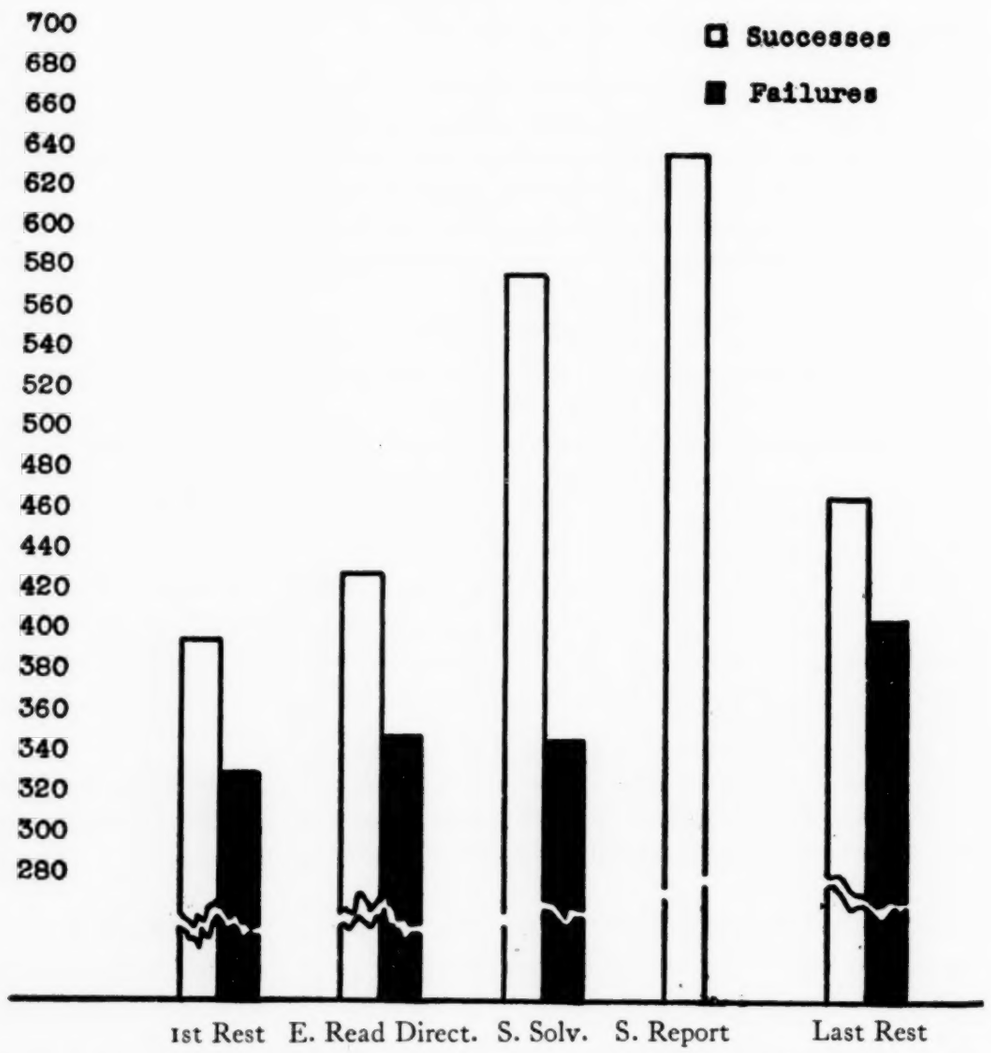

FIG. 5. Sum in mm. of deflections per sec. during each of the activities specified for successful and failing subjects as per photographs taken from oscillograph records.

initial and final rest periods, so it can be concluded that the great increase in muscular tensions in the case of successful subjects is a function of the work in progress during solving

and reporting. Failing subjects do not show this increase in action potentials during attempted solution. A check of the individual cases reveals that 14 of the 15 successful subjects for whom photographs were secured exhibited more action potentials during solution than during initial rest and the tensions during final rest were less in 10 of the 14 cases for whom data were secured than during solution of the problem. Only seven of the 12 unsuccessful subjects exhibited more action potentials during solution than during initial rest. Five of these increases were slight and the other people who did show decidedly more action potential during solution felt bad because of their failure and plainly showed that they had been working hard to get the problem. The other five people exhibited decidedly lower action potentials during solution than during rest. In all cases of failure but two, the tensions during final rest were higher than during attempted solution.

Inspection of Table III reveals that there is a tendency for successful subjects to hold the hand on the tambour more quietly while solving the problem than during a period of rest preceding or following such mental work, but they tend to be more active muscularly during report than during either rest period. Failing subjects, on the other hand (see Table IV), tend to exert less activity during the rest periods than do subjects who succeed. Failing subjects do not materially change the amount of their muscular activity during mental work. Thus, it can be concluded that the successful subjects tend to be more active muscularly before and after mental work than do failing subjects but the amount of muscular activity of the forearm as registered by the tambour during solution by successful subjects has a tendency to decrease. The increase in action potentials of successful subjects as revealed by Table I is thus due to a stiffening of the muscles of the forearm and a consequent tendency to hold the hand more quietly on the tambour. In the group of 16 successful subjects thirteen of them held their fingers more quietly on the tambour during the solution than during initial rest. Change of sitting position by two of the other subjects resulted

in a large deflection of the tambour while the large change on the part of the other subject is very likely due to experimental error. During the final rest period, ten of the sixteen successful subjects registered more movement of the fingers than they did during solution. It can be seen from Fig. 6 that successful

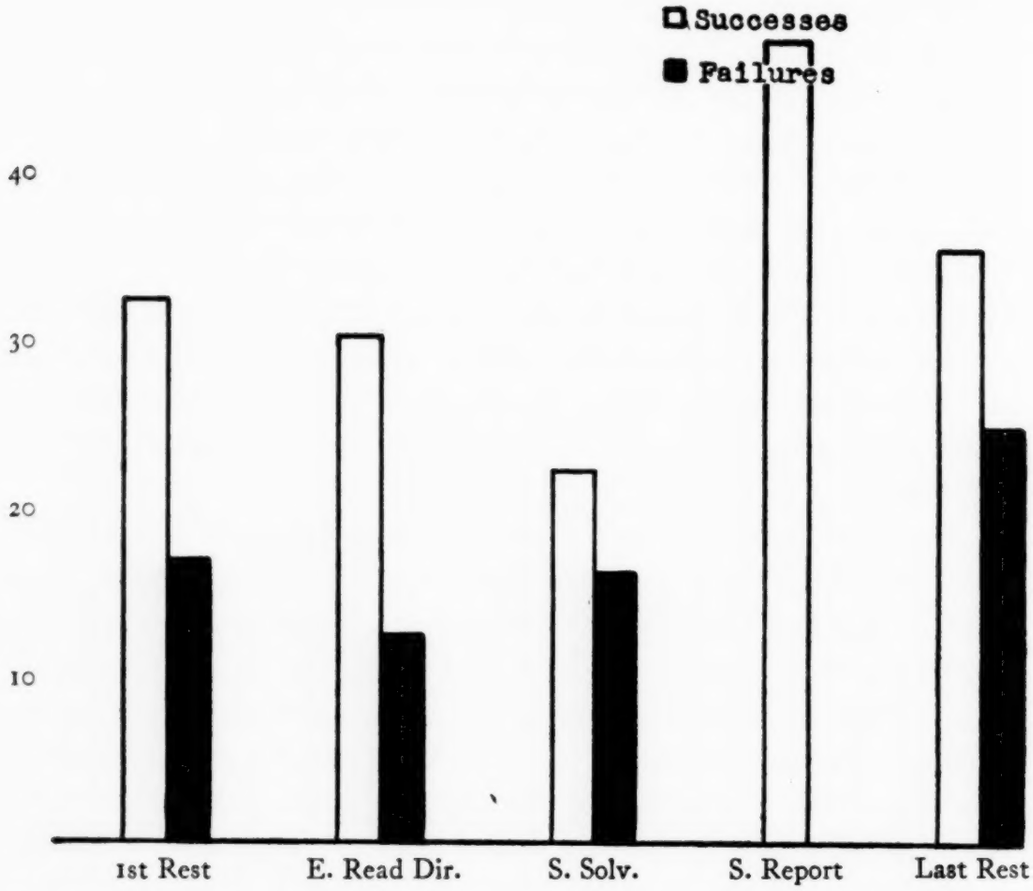

FIG. 6. Sum of the vertical movements in mm per min. made on the kymograph record by successful and unsuccessful subjects during the periods specified.

subjects tend to be physically more active than failing subjects during initial rest, reading of the problem and final rest. The difference between the activity of the two groups during solving is insignificant.

During problem solving those who succeed tend to stiffen and straighten their fingers, thus letting the tambour indicator drop. The pressure is noticeably less during solution than it is during the rest period before solving and it also tends to be lower during solution than during the final rest (see Table V). There is only a slight tendency in the same direction in the case

of failing subjects (see Table VI). The pressure for successful and failing subjects does not differ greatly during any of the periods (see Fig. 7). Thus, it can be concluded that the decrease in pressure noted during problem solving by successful subjects is an accompaniment of successful problem

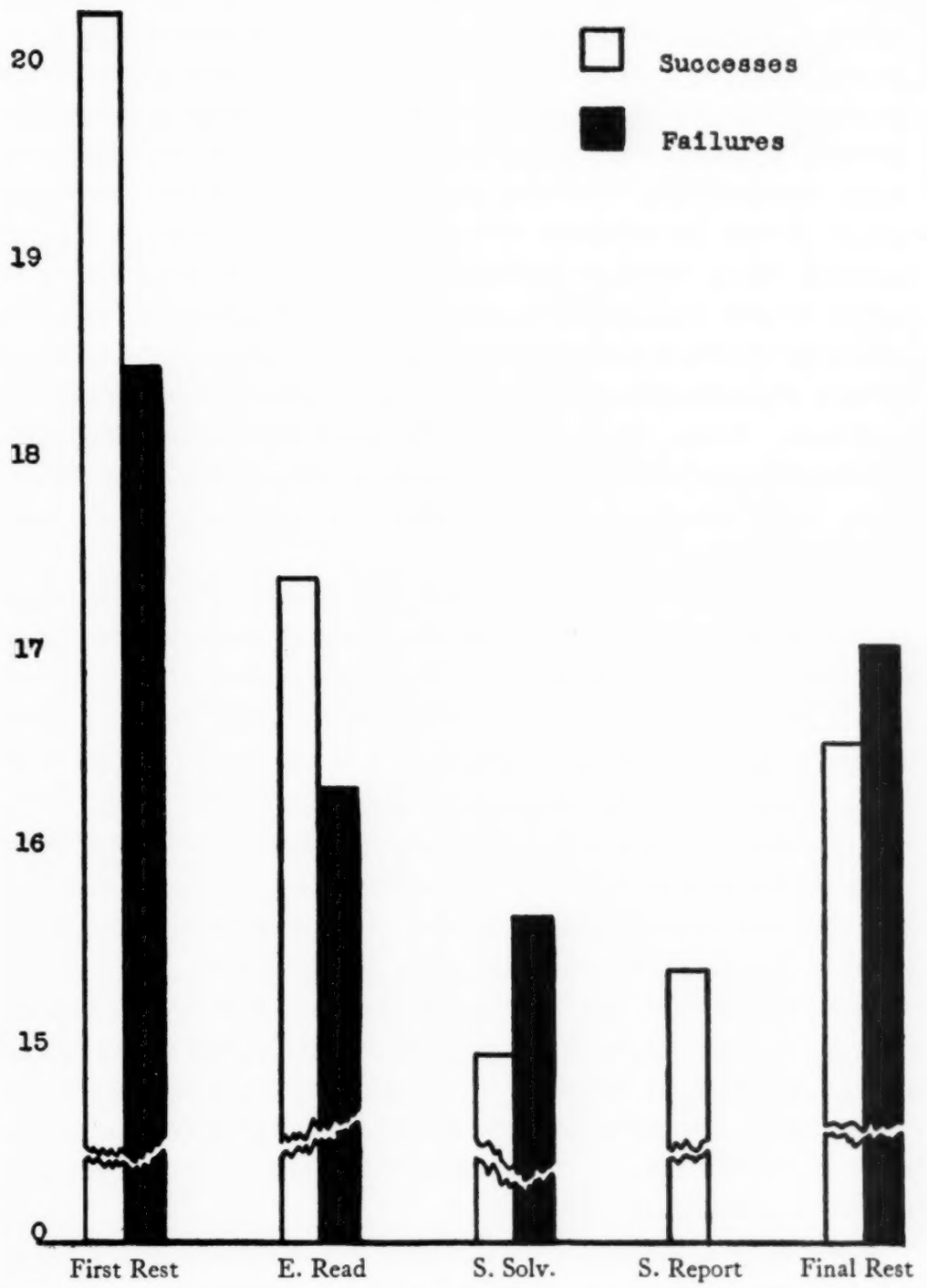

FIG. 7. Average grip pressure exerted on the tambour during the activities indicated.

solving. The high correlations of + .72 for first rest vs. solving and of + .91 for final rest vs. solving reveal the fact that any tendency of the group is also characteristic of the individuals composing the group. Furthermore, upon inspection of the kymograph records it will be noted that 12 of the 16 successful subjects registered less pressure during solving and they also held their tambours more steadily than during rest. The four subjects who did not exert less pressure during solving completed the problem within 27 seconds and all four reported that they had to put forth but little effort to solve the problem. In the case of failing subjects, however, seven of the 12 subjects did not exert less pressure during solution than during problem solving. Three of the five subjects who did exhibit such a decrease in pressure did make partially successful reports and another subject was stopped by the experimenter just before he succeeded in solving the problem. Thus, the data seem to show that the stiffening of the fingers and increased steadiness in the grasp of the tambour are functions of successful or partially successful problem solving.

The question might arise as to whether the differences above noted are functions of time spent in working or of successful and failing work. The summation of the movements of the fingers of successful subjects who worked more than 50 seconds [4] is practically the same as for those who worked less than this amount of time (see Table VII). The summation of movements of failing subjects working more than 50 seconds is noticeably greater than for those working less than 50 seconds and is in the same direction as for both groups of successful subjects (see Table VII). It is to be further noted that the successful subjects who worked more than 50 seconds to solve the problem are the ones who showed a large decrease in muscular movement as compared with the rest periods. Hence, it seems that the decrease in this movement is a function of perseverance and success rather than of length of time spent in work.

[4] Fifty seconds was arbitrarily chosen as a dividing line because half of the successful subjects worked less than 50 seconds and half worked for a longer time.

In the case of action potentials per second as registered by the photographs, the differences in averages between those spending little time in solving and those spending more time in solving are insignificant (see Table VIII). This statement holds for successful and failing subjects. Thus, it can be concluded that the great increase in action potentials during successful solution is a function of successful mental work and is not a function of the amount of time spent in solving.

The grip pressure in the case of successful subjects spending more than 50 seconds in solving the problem is slightly higher than for those who worked less than 50 seconds, but this difference is not reliable. In the case of failing subjects, the differences are in the opposite direction but these differences are not reliable either (see Table IX). Hence, the decrease in grip pressure during successful mental work of this kind is not due to the time spent in solving, but is an accompaniment of successful work.

It might be assumed that release of pressure on the sub-

TABLE VII

COMPARISON OF SUMMATION OF MOVEMENTS PER MINUTE FOR THOSE WHO WORKED LESS THAN 50 SECONDS AND FOR THOSE WHO WORKED MORE THAN 50 SECONDS. (SUCCESSFUL SUBJECTS AND FAILING SUBJECTS ARE LISTED SEPARATELY.)

Successes

	No. Cases	First Rest	Read. and Directions	Solving	Report	Final Rest
Worked less than 50 sec.	8	16.4	23.0	19.6	38.3	22.4
Worked more than 50 sec.	8	47.4	35.6	22.3	50.3	47.0
Difference		31.0	12.6	2.7	12.0	24.6
$\frac{\text{Difference}}{\text{S.D. (Diff.)}}$		3.1	2.2		.6	3.9

Failures

	No. Cases	First Rest	Read. and Directions	Solving	Report	Final Rest
Worked less than 50 sec.	4	10.7	8.5	7.5		26.9
Worked more than 50 sec.	8	19.4	13.4	23.7		22.8
Difference		8.7	4.9	16.2		4.1
$\frac{\text{Difference}}{\text{S.D. (Diff.)}}$		1.2	1.2	2.2		.7

TABLE VIII

COMPARISON OF SUMMATION OF ACTION POTENTIALS (PHOTOGRAPH RECORD) PER SECOND FOR THOSE WHO WORKED LESS THAN 50 SECONDS AND THOSE WHO WORKED MORE THAN 50 SECONDS. (SUCCESSFUL AND FAILING SUBJECTS ARE LISTED SEPARATELY.)

Successes

	No. Cases	First Rest	Read. and Directions	Solving	Report	Final Rest
Worked less than 50 seconds	8	368	465	572	614	457
Worked more than 50 seconds	8	388	394	573	685	469
Difference		20	71	1	71	12
$\frac{\text{Difference}}{\text{S.D. (Diff.)}}$		.15	.5	.01	.27	.08

Failures

	No. Cases	First Rest	Read. and Directions	Solving	Report	Final Rest
Worked less than 50 seconds	4	294	328	313		354
Worked more than 50 seconds	8	387	376	377		355
Difference		93	48	64		1
$\frac{\text{Difference}}{\text{S.D. (Diff.)}}$		1.2	.6	1.5		.7

TABLE IX

COMPARISON OF RECORDS OF AVERAGE HEIGHT ABOVE THE BASE LINE FOR THOSE WORKING LESS THAN 50 SECONDS AND THOSE WORKING MORE THAN 50 SECONDS. (RECORDS FOR SUCCESSES AND FAILURES ARE LISTED SEPARATELY.)

Successes

	No. Cases	First Rest	Directions	Solving	Report	Final Rest
Worked less than 50 sec	8	18.0	13.8	13.5	14.7	14.8
Worked more than 50 sec	8	22.6	18.1	16.1	16.1	18.6
Difference		4.6	4.3	2.6	2.4	3.8
$\frac{\text{Difference}}{\text{S.D. (Diff.)}}$		1.7	.8	.7	.6	1.7

Failures

	No. Cases	First Rest	Directions	Solving	Report	Final Rest
Worked less than 50 sec	4	21.1	17.5	17.3		18.9
Worked more than 50 sec	8	15.8	15.1	13.7		15.3
Difference		5.3	2.4	3.6		3.6
$\frac{\text{Difference}}{\text{S.D. (Diff.)}}$		1.1	.5	1.1		1.3

ject's tambour would be indicative of a decrease in muscular tensions in all cases but this decrease in tension on the tambour might be due in some cases to lifting the fingers and; hence, an increase in muscular tension. It has been pointed out in the foregoing pages that the significant difference between successful and failing subjects so far as action potentials are concerned occurs during the solving period. Successful subjects exhibit more action potentials during problem solving than during rest while failing subjects do not (see Tables I and II). When the vertical movements of the tambour indicator are investigated (see Fig. 6) it is found that successful subjects tend to be more active during the rest periods and during the reading periods than are failing subjects. During the solving period the successful subjects decrease the amount of their activity to the extent that there is little difference between their muscular performance and that of failing subjects (see Fig. 6). Study of the grip pressure changes reveals that successful subjects tend to grip the tambour tighter during initial rest than do failing subjects. Those who succeed definitely release this grip during solving while those who fail tend to maintain the same amount of grip pressure during solving as during rest. Thus, it can be seen that the differences between successful and failing subjects is in the solving period when action potentials and grip pressure are investigated but it is in the rest periods when muscular motion is considered. There is a slight negative correlation between action potentials and muscular movements when we consider the data in terms of broad categories.

In order to test the relationship between action potentials, muscular motion and grip pressure, correlations were computed.

The following tables indicate the correlation between the

TABLE X

CORRELATION BETWEEN ACTION POTENTIALS AND SUM OF THE VERTICAL MOVEMENTS DURING EACH OF THE ACTIVITIES INDICATED

	Initial Rest	Directions by E	Solving by S	Report by S	Final Rest
r	−.11	+.21	+.11	−.35	−.01
S.D.$_r$	±.262	±.254	±.262	±.233	±.266

TABLE XI

CORRELATION BETWEEN ACTION POTENTIALS AND AVERAGE PRESSURE EXERTED DURING EACH OF THE ACTIVITIES INDICATED

	Initial Rest	Directions by E	Solving by S	Report	Final Rest
r	−.12	−.10	−.08	−.20	+.15
S.D.$_r$	±.262	±.265	±.265	±.254	±.262

TABLE XII

CORREATION BETWEEN TOTAL VERTICAL DISTANCE MOVED AND AVERAGE PRESSURE EXERTED DURING EACH OF THE PERIODS INDICATED

	Initial Rest	Directions by E	Solving by S	Report by S	Final Rest
r	+.14	−.26	−.06	−.05	−.10
S.D.$_r$	±.262	±.248	±.265	±.265	±.264

various performances measured in this division of the research. The successful and failing subjects were thrown together for these computations.

The foregoing group of tables indicates that there is a very small correlation between the various performances studied in this division of our research when the data are considered in terms of narrow categories. In no case is the correlation either positively or negatively significant and in many cases the standard deviation of the correlation is larger than the correlation itself. This leads us to conclude that the action potentials during problem solving are not directly related to muscular movement or the grip pressure in such a situation. Neither is there a direct relationship between the sum of the muscular movements and the grip pressure.

CONCLUSIONS

I. Successful problem solving in this situation is accompanied by:
   a. Increase in action potentials,
   b. Decrease in overt movements of the muscles of the forearm,
   c. A tendency to stiffen and straighten the fingers, thus releasing the grip.

II. Unsuccessfull problem solving in this situation tends to be accompanied by:
   a. Same amount of tension during attempted solving as during previous mental rest, but there are less potentials during attempted solving than during a subsequent period of rest.
   b. Less overt movement of the forearm during the presentation of the problem and the same amount of movement during attempted solving as during the period of initial rest. During the period of subsequent rest there tends to be more movement than during presentation of problem or attempted solving.
   c. Maintenance of the same grip tension during attempted solution as during preceding and subsequent rest.

III. Successful and unsuccessful subjects exhibit practically the same amount of action potentials during initial rest; successful subjects exhibit greater action potentials than unsuccessful subjects during problem solving of this kind.

IV. Successful subjects tend to be muscularly more active during initial rest, final rest and hearing of problem than do failing subjects. However, successful subjects decrease the amount of their muscular activity during problem solving so that there is little difference between the two groups.

V. Successful and failing subjects register practically the same amount of grip pressure during initial and final rest. Also, the difference during problem solving is insignificant but when the grip for successful subjects during problem solving is compared with that during initial rest for the same group, the difference approaches significance.

VI. There is practically a zero correlation between:
   a. Action potentials and localized muscular movements.
   b. Action potentials and grip pressure.
   c. Muscular movements and grip pressure.

Part IV

Summary of the Series of Articles [5]

In this research an investigation has been made concerning the rate of involuntary winking, the skin resistance to an electric current, action potentials, muscular movements, and grip pressure during rest periods as compared with these activities during problem solving by successful and unsuccessful subjects.

Successful problem solving is accompanied by greater increase in rate of involuntary winking than is unsuccessful problem solving. The significant difference between successes and failures lies in the rest periods. The skin resistance to an electric current drops much more in the case of successful problem solving than in the case of unsuccessful work on problems of this kind. During successful work the action potentials are much more prominent than during unsuccessful work. The muscular movements decrease more in the case of successful solving than in the case of unsuccessful problem solving. The difference between successes and failures in this case is in the rest periods preceding and following the working period. The grip tension decreases during successful problem solving and it is suggested that this is due to straightening and stiffening the fingers.

It is suggested that these changes in performance may be due to arousing the individual to make a response. The conclusion is drawn that (1) muscular activity is increased during problem solving, or (2) Problem solving is identical with this increase in activity. This explanation is offered as a substitute for the 'overflow hypothesis.'

Bibliography

1. Bills, Arthur G., The influence of muscular tension on the efficiency of mental work, *American Journal of Psychology*, 1927, **38**, 227–51.
2. For more extended bibliography, see Article I.

[5] See two previous issues of this journal.

CHANGES IN THE PITCH OF TONES WHEN MELODIES ARE REPEATED

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In a recent volume of this journal [1] Guilford and Hilton reported the results of a study on the shifts of pitch in tones of a melody when the melody is repeated with one of the tones altered to the extent of a semi-tone. The following conclusions were reached: (1) "The tones, altered or unaltered, seem to be rendered unstable by the presence of the other tones in the melody. The longer the melody the more unstable they become. The unaltered tones are more stable at the beginning than at the end of the melody, and at either end than they are in the middle. By stability is meant a close correspondence between physical and phenomenal fact." (2) "The first tone in a melody tends on the average to seem raised in pitch when the melody is repeated, and the last tone seems to be lowered in pitch." (3) "When one tone is raised or lowered, all the other tones in the melody tend to change along with it in the same direction." (4) "The dynamic effect of the altered tone is apparently greater with those tones which come before than with those that come after it."

It was admitted in the study just referred to that we cannot be sure whether all the phenomenal shifts in pitch are due to the one altered tone; whether some of them are due to the mere repetition of the melody, aside from any alteration. It is unlikely that result number (3), the shift of the unaltered tones in the same direction as the altered tones, could have been produced by repetition of the melody alone. But until we can eliminate the possible effects of mere repetition from the apparent shifts in pitch, we cannot be sure how much those apparent shifts are due to the factor of repetition. A

[1] J. P. Guilford and R. A. Hilton, Some configurational properties of short musical melodies, THIS JOURNAL, 1933, 16, 32–54.

series of control experiments therefore seemed necessary in which no tones were altered in the second playing of the melodies, and that is what we wish to report here.

The Seashore test record for Musical Memory, which had been used by Guilford and Hilton, was remade without the altered tones at the University of Iowa laboratory.[2] Ten *O*s, including two instructors, six graduate students and two undergraduates, served throughout the experiments. Half of this number had had varying degrees of musical training, but their results did not differ significantly from those of the other *O*s. At the beginning and near the middle of the series of experiments, tests were made of the pitch discrimination of the *O*s. Using the B side of the Seashore test record for pitch discrimination, and applying the method of right and wrong cases (with Urban's weights) to the data, the *DLs* of our ten *O*s were found. They ranged from 1.37 dv. to 6.83 dv., with a mean of 3.10 dv. These *DLs* compare very well with those of the *O*s in Guilford and Hilton's study. In the latter the mean *DL* (using the same methods) was 2.94. This equivalence of discriminating power for the *O*s in the two studies is important because we wish to compare the extents of the phenomenal changes occurring in the two.

The ten *O*s observed in a group as in the previous study. At each playing of the record one particular tone in each melody would be singled out for observation, *e.g.*, the second in all melodies, the fifth, or sixth, as the case might be. *O* was instructed to report whether the tone as it came the second time was higher than, lower than, or equal to the same tone the first time the melody was played. Two other categories were permitted although not often employed. One was 'doubtful' when *O* noticed a change but was not sure whether it was upward or downward in pitch. The other was 'questionable' when *O* could make no report at all, due to lapse of attention, failure of criteria, or for other reasons. Every *O* judged the 200 tones 20 times each, making 40,000 judgments in all, or 200 judgments for every tone. In this

[2] We wish to express here our great indebtedness to Dean C. E. Seashore who placed the equipment of his laboratory at our disposal, and to Dr. D. A. Rothschild who supervised the preparation of the records.

study as well as in the former one, we have pooled the judgments of all *O*s. While this procedure undoubtedly glosses over individual differences, it gives a picture of the *typical* phenomenal shifts. If there were no general agreement at all as to the shift of a particular tone, the final pooled measurement of shift would be zero. It is better, we believe, to depend upon 200 judgments made by ten different *O*s than to obtain 200 judgments from a single *O*. A single *O*, hearing the repeated melodies a large number of times comes to form habits and convictions which stabilize his judgments in a certain direction. It might even have been better to use 20 *O*s each judging the tones ten times to avoid the crystallizing of constant errors. On the other hand, it is desirable that an *O* judge tones under these conditions a number of times in order to establish dependable and consistent criteria.

The Instability of Tones in a Melody

The results of this study, more strikingly than before, demonstrate the fact that a tone in a melody has an uncertain pitch and is rarely heard twice as having the same pitch. On the whole, less than 25 percent of all the judgments were in the 'equal' category. No melody had a tone with 100 percent equality judgments. The greatest proportion for any one tone was .410, in one of the two-tone melodies. The smallest proportion was .045 in one of the six-tone melodies. The mean proportion was .244. It is to be granted that the same tone repeated alone, not within the influence of the pattern of a melody, would be judged 'equal' in only a fraction of the cases. This is demonstrated, too, in the comparison of identical weights. But in comparing identical isolated stimuli one expects to obtain say 40 or 50 percent equality judgments.

The longer the melody the smaller were the proportions of equality judgments. They were .318, .273, .248, .253, and .196 for melodies with two to six tones respectively. The proportion of doubtful (change with uncertain direction) judgments increased with the length of the melody as follows: .025, .035, .039, .040, and .041 respectively. These results

may be explained in part by the fact that the time interval between the pairs of tones to be judged increased with the length of the melody. But judging from other studies of the influence of time interval alone, this factor should not be expected to have sufficient force to explain these data. Besides, the increase of time due to the addition of one more tone to the melody is less than one second. Another, and probably more important factor, is the increase in the number of intervening tones between the two to be compared. Not that the intervening tones serve as distractors in the usual sense, but that they tend to shift the 'ground' or basic neural traces of the first tone before the second tone comes.[3] But these inter-dynamic effects of one tone upon another are precisely the melodic effects upon single tones, or at least one phase of those effects, that we have been insisting upon. An interesting side-light was the fact that most of the *O*s refused to believe that the tones were physically of the same frequency when they were so informed after the experiments were over. Only the writers knew beforehand that the melodies were so played.

Since all pairs of tones that were compared were of the same frequency and the *O*s had no actually differing pairs to judge which might have served, by contrast, to stabilize the unaltered tones, is it possible that we obtained an undue proportion of non-equality judgments? Reference to the study by Guilford and Hilton will show that this is probably true, although a different group of *O*s was involved there.[4] The proportions of equality judgments for the unaltered tones in that study were .759, .622, .620, .598, and .586 for melodies with two to six tones, respectively. Compare these with the list given above: .318, .273, .248, .253, and .196. When there were physically altered tones to be judged also, with differences as great as semi-tones, the proportions of 'equal' judgments are more than doubled. The processes of human judgment of simple sensory reactions are decidedly complex,

[3] As in the comparison of two lifted weights when a third weight is inserted between them; see J. P. Guilford and D. G. Park, The effect of an interpolated weight upon psychophysical judgments, *Amer. J. Psychol.*, 1931, 43, 589–599.

[4] *Op. cit.*, 39.

with many determining factors, but by painstaking variation of conditions we will yet learn their secrets.

There is nothing in the results of the present study to verify the remainder of conclusion (1), that the stability of tones is greater near the beginning than near the end of the melody. There is only the slightest support for the conclusion that the stability is greater at the ends than in the middle. The proportions of 'equal' judgments averaged .233 for first tones, .225 for middle tones, and .232 for last tones in the melody. It would seem reasonable that the former conclusion should hold, in the same way that the ends of a series of memorized items suffer less interference and hence are easier to retain.

Phenomenal Shifts in Pitch

The procedure for estimating the direction and amount of change in pitch was as follows: For every tone, the proportion of the non-equal judgments that were in the category 'greater' were tabulated. There were from 104 to 184 non-equal judgments for every tone, the average tone receiving approximately 150 judgments of either 'greater' or 'less.' Assuming that individual judgments are independent of one another we may say that any proportion deviating from .500 by more than .067 is fairly significant; there is one chance in twenty that as great a deviation would be obtained by chance alone. This is based upon the case when N equals 150. Chance alone would lead us to expect only ten proportions deviating more than .067 from .500. As a matter of fact 163 proportions or almost five out of six deviated more than .067. The smallest proportion was .120, in one of the three-tone melodies, and the largest proportion was .858 in one of the four-tone melodies.

Following the procedure of Guilford and Hilton, we translated the proportions into PE units, assuming the principle that "equally often noticed differences are equal, unless always or never noticed." It was expected that this would give the amount of shift of a tone more nearly in terms of equal psychological units than would the proportions themselves, although as was pointed out before, the conclusions

finally reached would probably be the same whether proportions or PE scale values are employed. If we accept a deviation of .067 from .500 to be relatively significant, then a shift of .250 PE will be equally significant; that is, a shift in pitch greater than plus or minus .250 PE units would occur by chance only once in twenty times.

There is nothing in the data to verify Guilford and Hilton's conclusion that in the repeated melody the first tones tend to rise in pitch and the last tones tend to fall in pitch. This is a phenomenon, which, if real, could occur without actual change in any tone such as we have in the original Seashore record. When no tones are altered, the average phenomenal shifts in first and last tones (based upon fifty melodies) are + .053 and + .096 respectively. The *O*s were likewise about evenly divided as to any introspective opinions on this point.

The conclusion that the shift in pitch of the unaltered (U-tones) tends to follow the shift of the altered tones (A-tones) is fully borne out by the present results. There is nothing in the repetition of the melodies alone to account for the consistent and systematic results obtained by Guilford and Hilton. The average results for melodies of different length are given in Table I, showing a comparison of the phenomenal shifts found in the corresponding tones in the two studies.

TABLE I

PHENOMENAL SHIFTS IN THE PITCH OF TONES IN REPEATED MELODIES, EITHER WITH OR WITHOUT ONE OF THE TONES BEING ALTERED

Length of Melody	With Repetition Only				Repetition with Altered Tone			
	A-tones		U-tones		A-tones		U-tones	
	A-tone Higher	A-tone Lower	A-tone Higher	A-tone Lower	A-tone Higher	A-tone Lower	A-tone Higher	A-tone Lower
2	.237	−.134	.064	.074	2.515	−2.668	.963	−.527
3	−.458	.230	.463	−.122	1.405	−2.014	1.027	−.429
4	.266	−.027	.325	−.202	2.898	−1.933	.438	−.697
5	−.314	.690	.061	.025	1.311	−1.596	.355	−.351
6	.575	.492	.028	.085	1.208	−1.160	.121	.027
All	.014	.235	.148	−.022	1.919	−1.785	.438	−.264
N	27	23	77	68	27	22	73	70

The changes indicated by the left half of Table I constitute the 'control' experiment. They are changes that occur from the mere repetition of the melodies. The shifts are rather unsystematic in extent, but the general trend is for a slight increase in pitch. Certain it is, that there is nothing present in the mere repetition of a melody which gives the almost universal net effect found in the last two columns;[5] the average tendency for the U-tones to rise or fall with the A-tone. The one exception found in the last column, a positive average of .027 in the six-tone melody, would become slightly negative if we deduct from it the corresponding mean of .085 when there was no A-tone present. We have not presented differences, or averages of differences, between the 'control' results and the 'experimental' lest those differences give undue numerical importance to the values in Table I. It is likely, also, that the effect of an altered tone combined with the effect of repetition is not merely an additive one. But it can be seen that if differences were found between the two halves of Table I, it would not at all change the systematic trends in the results of Guilford and Hilton, and in fact would improve the trend in the single case just pointed out.

The control experiments emphasize the fact that the shifts in pitch are subject to many factors other than the altered tone. Those factors have differing consequences in different melodies and probably at different positions in the melodies. The averages in Table I tend to smooth over those great variations from melody to melody. The most extreme rise in pitch was equal to 1.588 PE units and the greatest fall in pitch was a minus 1.742 PE units. Is it any wonder, then, that with these same heterogeneous factors still operating when there is an altered tone the other tones (U-tones) in the melody do not always rise or fall with it? Is it any wonder that the averages of the last two columns are no greater than they are? And yet, in spite of the strong variable errors the trend for the U-tones to follow the A-tones consistently appears in the averages.

Guilford and Hilton found the unexpected result that the

[5] These columns are reproduced from Guilford and Hilton's study, p. 48.

U-tones preceding the A-tones in the melody were on the whole shifted more than were those following the A-tones. Could this have been due to 'accidental' influences such as the effect of repetition? Table II shows a comparison of the corresponding tones with and without A-tones. The control experiments of this study tend to reduce the differences between the preceding and following U-tones slightly, but not sufficiently to destroy a strong presumption in favor of the original conclusion.

TABLE II

CHANGES BEFORE AND AFTER THE A-TONES

	Before		After	
	A-Tone Higher	A-Tone Lower	A-Tone Higher	A-Tone Lower
A-tone present.....	.532	−.366	.480	−.184
A-tone absent.....	.104	−.081	.192	.034

A common introspection made by the *O*s was to the effect that in ascending melodies the tones in the repeated melody seemed as a rule to be higher whereas in descending melodies the opposite seemed to be true. As a matter of fact, in both types of melody the average net shift is slightly positive. Contrary to expectation, the five descending melodies gave an average shift upward of .271 PE units and seven ascending melodies gave an average upward shift of .133 units. This may be taken to mean very little, except perhaps that such introspections are merely deceptive opinions and not descriptions of actual facts.

There is one more obvious source, in addition to repetition, in which to look for the phenomenal shifts which were discovered by Guilford and Hilton, and that is in the physical variations in the flute tones of which the melodies are composed. But granted that a player of the flute can produce variations in frequency, would he make deviations which psychologically are rated equal to a fourth or fifth of a semi-tone, on the average, some being indeed greater than those changes produced by the A-tones which are known to be deviations of a semi-tone? And would the flute player make

his deviations in a systematic manner demanded by the general trends of our results? To assume this would shift the problem to the psychology of flute-playing. A more likely disturbing factor is a variation in timbre of the tones. A change in the actuation of a tone on the flute might add or subtract from the higher overtones, giving a consequent appearance of a rise or fall in pitch. An inadvertent change in intensity may also come in at times. Our *O*s reported a few such instances. It is possible for the trained *O* to ignore to some extent these secondary changes, but they might still have an influence upon the judgments. It is doubtful, again, whether accidental variations in timbre or in intensity could be great enough, or could come in just the systematic manner that would be demanded to account for the systematic trends which require explanation. And if they come in an unsystematic manner, unsystematic so far as the trends are concerned, they would rather tend to obscure the trends by introducing variable errors than to produce or even to enhance them. We doubt very much, then, whether any inadvertent variations of the tones in pitch, intensity or in timbre are of sufficient amount or are systematic enough to produce the fundamental trends which we have found in melodies.

Summary and Conclusions

In order to test some conclusions reached by Guilford and Hilton concerning the effects of the alteration of the pitch of one tone in a short melody, some control experiments were performed in which the same melodies were repeated without any alteration, the repeated tones being compared one by one. In agreement with the conclusions of the previous study are:

1. Tones in a melody are very unstable. Under the conditions of this study they are reported changed in pitch in more than 75 percent of the cases.

2. When one tone is altered in pitch in the second playing there is a tendency for other tones to follow by shifting in the same direction. This is not due to the repetition of the melody.

3. Neither is mere repetition of a melody responsible for the fact that tones preceding the altered tone are more affected on the average than tones following it.

There was nothing in the results of this study to verify the conclusions that:

1. A tone is more stable near the beginning of a melody than near the end. And there is only the slightest indication that terminal tones are more stable than middle ones.

2. First tones in a melody tend to rise in pitch on being repeated and final tones tend to fall.

(Manuscript received January 7, 1935)

THE RELATION OF AFFECTIVE TONE TO THE RETENTION OF EXPERIENCES OF DAILY LIFE *

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INTRODUCTION

The question of the relationship between the pleasantness and unpleasantness of experiences and their retention continues to be a vigorous problem. The general question may be broken into two subsidiary problems: 1. Does pleasantness favor retention more than unpleasantness; and 2, does the degree of pleasantness or unpleasantness bear any relation to retention. The present investigation deals with these two subsidiary questions.

Most of the investigations dealing with the relationship of feeling tone to retention have dealt with the retention and recall of words, figures, odors, puzzles, with association reaction times, and with free association. In Meltzer's [1] review there are but two studies, those of Kowalewski and of Wohlgemuth, that deal with the retention of pleasant and unpleasant experiences of every-day life such as form the subject matter of the present study. Since Meltzer's review two other studies [2] on the same topic have made their appearance.

* Research Paper No. 351, Journal Series, University of Arkansas.

[1] For a summary of the studies prior to 1930 see H. Meltzer, The present status of experimental studies of the relationship of feeling to memory. *Psychol. Rev.*, 1930, **37**, 124–139.

[2] Ruth H. Thompson, An experimental study of memory as influenced by feeling tone, J. EXPER. PSYCHOL., 1930, **13**, 462–468; A. Jersild, Memory for the pleasant compared with the unpleasant, J. EXPER. PSYCHOL., 1931, **14**, 284–288. Some data collected in a manner scarcely comparable to these two and to the experiment here reported are given by H. Cason, The learning and retention of pleasant and unpleasant

In these papers recalls were taken after a single period or at the most after two different intervals. Further, in none of these studies were the experiences given ratings corresponding to different degrees of pleasantness or unpleasantness, the subjects being simply asked to list and later recall experiences of a pleasant or unpleasant nature. In the present study the retention of such experiences over a much greater variety of intervals, some short and some long, was tested. In addition the subjects were asked to rate the experiences listed in terms of the degree of affective tone present at the time of the occurrence of the experience.

METHOD

The general plan and method of the study follows. In two successive years, 1932 and 1933, students in the psychology classes of the writers were given the following task at the start of the first meeting of the class after the Christmas vacation. On sheets of paper provided by the instructor the students were asked to list, briefly, all pleasant and unpleasant experiences they could possibly remember from the holidays just completed. They were urged to report all experiences or incidents remembered, no matter how trivial, that were at least discernibly pleasant or unpleasant. Anonymity with regard to the material was promised them. They were told to record experiences just as they remembered them with no effort to list them in separate columns of pleasant or unpleasant or in any other organized scheme. At the end of 15 minutes the students were asked to cease writing (as a matter of fact, perhaps only one person in 20 would still be writing at the end of the period allowed). They were then asked to go over their paper and mark each item with a symbol indicating the degree of unpleasantness or pleasantness which the experience had had at the time of occurrence. The marking system employed was that of using the numbers from 1 to 3 for the pleasant experiences, 1 indicating slightly pleasant experiences, 2 moderately pleasant, and 3 extremely pleasant experiences. Similarly −1, −2, and −3 were used to indicate increasing degrees of unpleasantness.

No intimation of the purpose of the experiment was given except that in response to inquiries from the class it was explained that the general topic being studied was that of learning. It was explained to each group that other classes were also to be tested and that for satisfactory experimental results it would be necessary for them to cooperate by refraining from all discussion of the experiment. After varying intervals, different groups of students were, without warning, given a second test of the same sort. The procedure was similar to that of the first recall in all save two respects. The subjects were told to treat this as a task entirely separate from their first recall—that if they could remember incidents that they had formerly reported they should enter those once more, but also, if they could now recall some things not remembered then that these items also were to be reported. The second change in instructions from the first

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activities, *Arch. Psychol.*, 1932, No. 134. An abstract of a paper given at the Ames meeting of the Midwestern Psychological Association by R. N. Menzies using data similar to ours appears in the *Psychol. Bull.*, 1933, 30, p. 574.

recall consisted in asking them to go over the papers a second time indicating in round numbers the number of times they had thought of each particular experience since it had occured. This was difficult for the students, of course, since they had not kept any such record but they were asked to give a rough indication of the frequency of such review. These second recalls were given after intervals of 2, 4, 7, 14, 28, 49, 70 and 140 days from the first recall.

A total of 245 subjects were used in the experiment, 163 in 1932 and 82 in 1933. The students ranged from sophomore to senior standing. Two classes employed (constituting 13 of the 45 students retested after 2 days, 13 of the 44 retested after 4 days, and 14 of the 46 retested after 7 days) were advanced classes composed of juniors and seniors. The remaining subjects were taken from sections of the general psychology course, composed primarily of sophomores, with a minor sprinkling of upperclassmen. The distribution of the subjects over the intervals tested is indicated in Table 1. Since separate treatment showed that the data for the two years taken

TABLE 1

SUBJECTS TESTED AT EACH INTERVAL

Year	2 days	4 days	7 days	14 days	28 days	49 days	70 days	140 days
1932.....	25	28	31	27	26		26	
1933.....	20	16	15			17		14
Total.....	45	44	46	27	26	17	26	14

singly revealed the same trend the results were combined and all the data were treated together in developing the following tables and graphs which picture the results of the experiment.

RESULTS

The first question in dealing with the results of the study concerns the retention of all pleasant and unpleasant experiences combined. In Table 2 are shown the means, with their

TABLE 2

PLEASANT AND UNPLEASANT EXPERIENCES RECALLED AT EACH INTERVAL

Interval	All Pleasant				All Unpleasant			
	1st Recall		2nd Recall		1st Recall		2nd Recall	
	Mean	Sigma	Mean	Sigma	Mean	Sigma	Mean	Sigma
2 days.....	13.2	1.1	12.8	1.0	7.3	.6	7.6	2.1
4 days.....	13.3	1.3	15.7	1.5	5.9	.5	6.1	.5
7 days.....	11.3	.9	12.5	1.1	5.6	.4	5.0	.5
14 days.....	8.7	1.0	9.00	.9	3.8	.3	4.2	.4
28 days.....	8.5	.7	8.4	.9	5.2	.4	3.9	.4
49 days.....	16.2	1.9	11.6	1.4	11.5	.8	8.2	1.4
70 days.....	9.6	.7	8.00	.5	5.3	.4	4.7	.3
140 days.....	13.5	1.6	8.8	.8	7.1	1.2	3.5	.4

standard errors, of all pleasant and all unpleasant experiences recalled at each interval. The ratios, for each interval, of the number of experiences listed on the second recall to the number listed on the first recall are plotted in Fig. 1.

Judging from the data of Table 2 and Fig. 1 there is no marked or consistent tendency for pleasant experiences to be retained better than unpleasant. At five of the intervals tested the ratios show a better relative retention of pleasant experiences and at the remaining three a better relative retention of unpleasant experiences are shown.

We turn next to a consideration of the data when classified according to the degree of pleasantness or unpleasantness of the experience reported. In Fig. 2 are shown the ratios of the second to first recall for the slightly pleasant, the moderately pleasant, and the very pleasant and for the slightly unpleasant, the moderately unpleasant, and the very unpleasant experiences at each interval.

While the ratios for the lower degrees of affective value show considerable fluctuation from interval to interval there are at least a few interpretative comments that seem to be justified. First, a comparison of the pleasant and unpleasant of the same degree of affective rating indicates that retention is not markedly a function of the qualitative differences in affective tone. In the second place, a comparison of the ratios for experiences of the same qualitative tone shows a rather consistent trend toward the better retention of experiences with the lowest affective rating. This is particularly marked at the two longest intervals. This seeming better retention of experiences low in affective rating is contrary to theoretical expectation and demands further analysis of our data.

The first step in this further analysis consists in considering our results when the experiences are discarded that were given only on the second recall. (Our discussion up to this point has been based on all of the experiences given on second recall.) In Fig. 3 are shown the ratios of second to first recall for all pleasant and all unpleasant experiences after this selection. In this comparison we have counted the experiences given on second recall without regard to the agreement

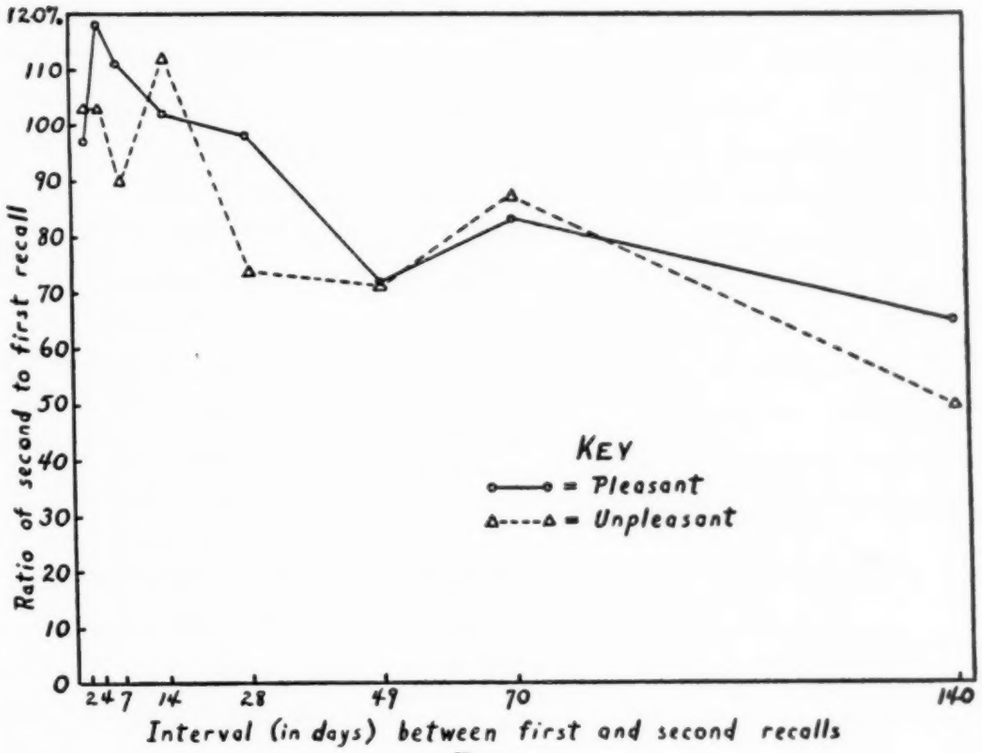
120%
110
100
90
80
70
60
50
40
30
20
10
0
Ratio of second to first recall
KEY
= Pleasant
= Unpleasant
2 4 7 14 28 49 70 140
Interval (in days) between first and second recalls

FIG. 1

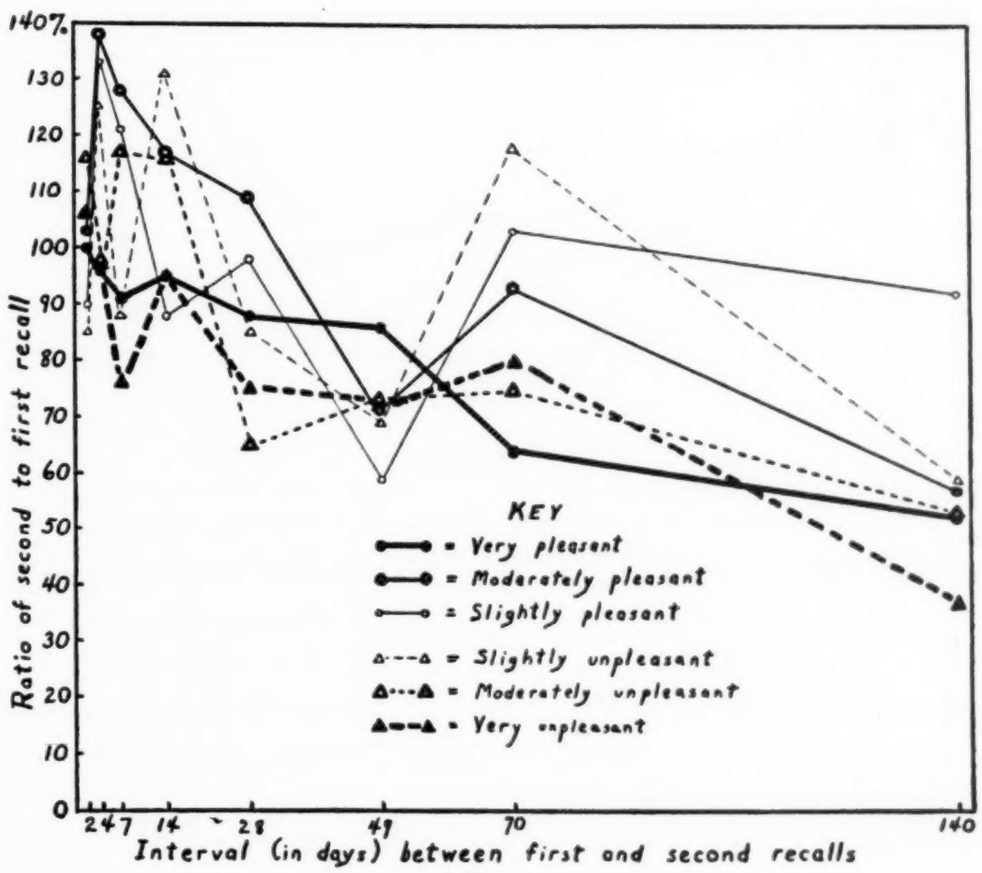
140%
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Ratio of second to first recall
KEY
= Very pleasant
= Moderately pleasant
= Slightly pleasant
= Slightly unpleasant
= Moderately unpleasant
= Very unpleasant
2 4 7 14 28 49 70 140
Interval (in days) between first and second recalls

FIG. 2

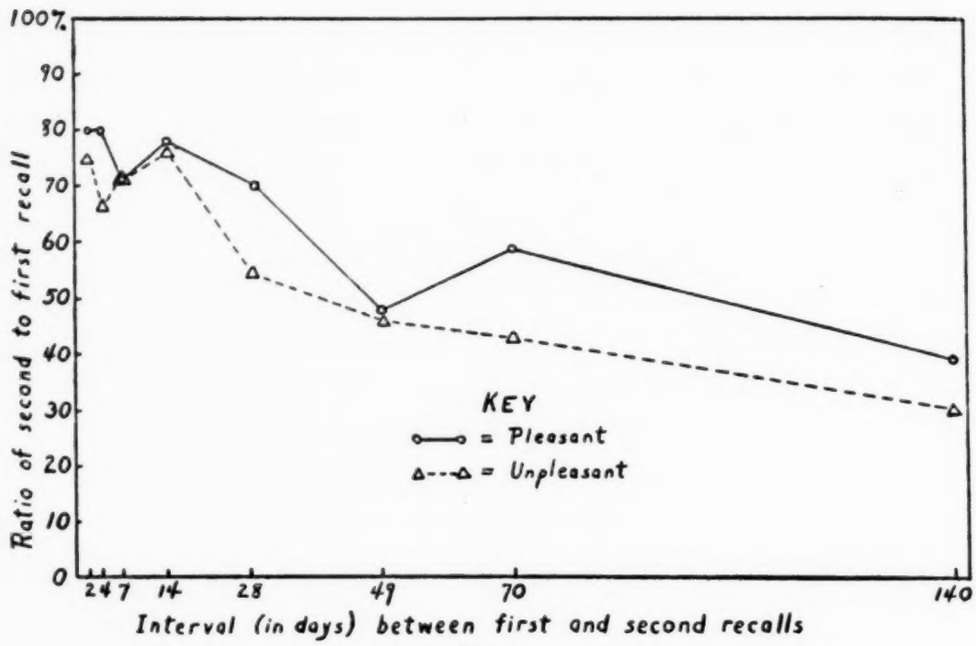

FIG. 3

or lack of agreement between the affective ratings given the experience on first and second recall. In Fig. 4 a similar treat-

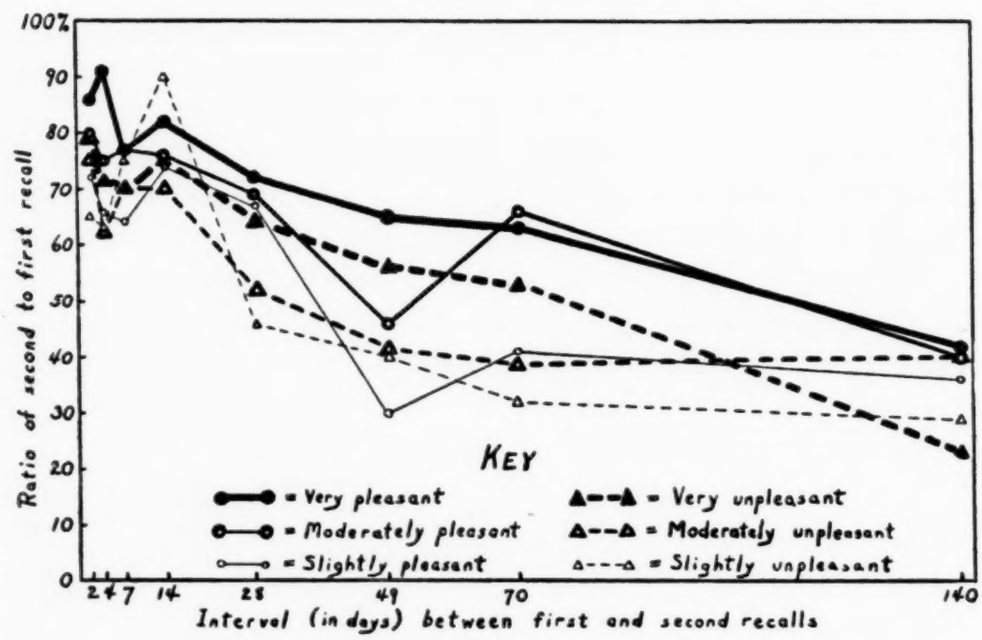

FIG. 4

ment has been accorded the experiences of different degrees of affective rating as assigned to the first recall, disregarding the rating given on the second.

Several things can be noticed as one examines the data of Figs. 3 and 4 and compares them with Figs. 1 and 2. In the

first place Fig. 3 indicates a slight but consistent tendency toward the better retention of the pleasant. Such a consistent tendency is lacking in Fig. 1. Secondly, in Fig. 4 there is manifested a marked trend toward the retention of pleasant experiences having a high affective rating as compared with those of lower affective rating. The same trend is present, though not so marked, with unpleasant experiences. This tendency is directly opposite that shown by Fig. 2 but agrees with the theoretical expectation of the better retention of experiences of considerable affective intensity. In the third place Figs. 3 and 4 agree with each other in showing a trend toward the better retention of the pleasant than the unpleasant experiences.

For a still more refined analysis of our data we turn to a consideration of the experiences reported in both first and second recalls with the same affective rating on the second recall as on the first. The data obtained by this more rigid selection yield the ratios of second to first recall shown in Fig. 5.

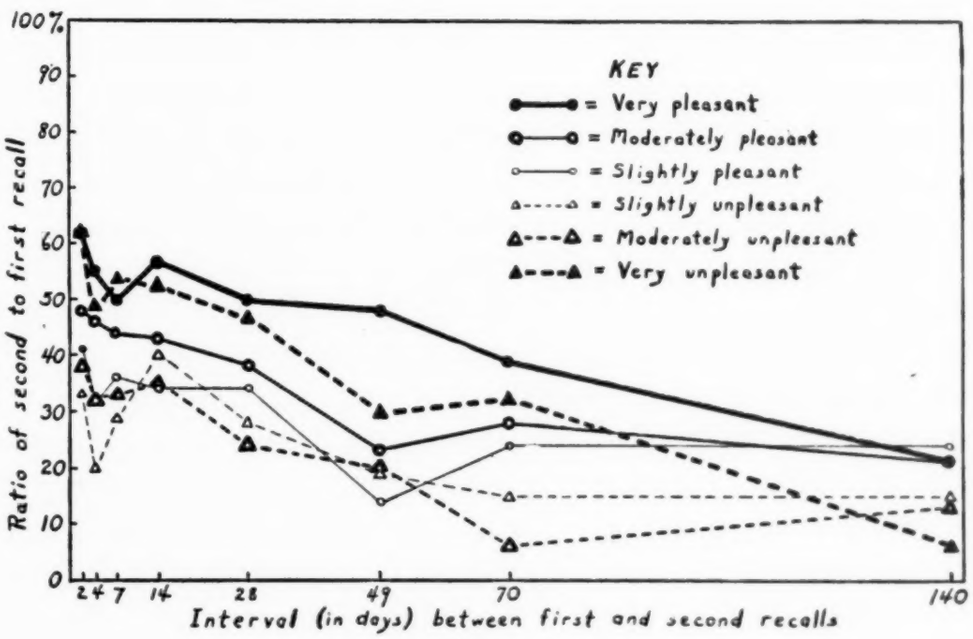

FIG. 5

The data of Fig. 5 serve to emphasize and corroborate those of Figs. 3 and 4: A slight trend toward the better retention of the pleasant in all categories and a marked tendency for the

better retention of experiences of highest affective rating, regardless of their qualitative nature. The values at each interval are lower in Fig. 5 than those in Figs. 3 and 4 as a result of the more rigid selection of the data utilized in the former.

Two features brought out by comparing Figs. 3, 4, and 5 with Figs. 1 and 2 should be mentioned. First, Figs. 1 and 2 indicate a more nearly equal retention of pleasant and unpleasant experiences when no experiences occurring in the second recall only are eliminated, whereas Figs. 3, 4, and 5 indicate a consistent trend toward the better retention of the pleasant when this elimination is made. From this comparison it necessarily follows that on the second recall more unpleasant than pleasant experiences were added by the subjects. Why this was the case is a puzzle, but there is some indirect evidence for believing that on the second recall the subjects listed some unpleasant experiences which they had not listed on the first recall because of embarrassment or other inhibitions; and, as a matter of fact, it might be argued that such embarrassment would tend to favor the subsequent recall of such rejected items. Whatever may be the correct explanation for the fact of more unpleasant experiences added in the second recall it is true that to eliminate all experiences not given on first recall results in an inadequate picture of the relative retention of pleasant and unpleasant experiences.

The second feature of interest in a comparison of these figures is the fact that Fig. 2, in which no elimination of experiences from the second recall was exercised, seems to indicate that experiences of low affective rating, particularly for the longer intervals, tended to be retained better than those of high affective rating, while just the opposite tendency is shown in Figs. 4 and 5. This contradiction leads to a consideration of the question whether any systematic shifts in affective ratings occurred with the passage of time. In considering this problem adequate conclusions can be drawn only when the nature and direction of such shifts are known. The affective ratings were certainly unreliable to some extent and it may be that the shifts were purely random in character,

occurring as often in one direction as in the other. On the other hand there may have been a systematic tendency for experiences to be given a more conservative rating with increased lapse of time. This latter, a systematic shift from the higher to the lower categories, is shown by the data of Table 3 to have been the case. In this table are given the

TABLE 3

NUMBER OF ITEMS SHIFTED FROM HIGHEST AFFECTIVE RATINGS ON FIRST RECALL TO LOWER RATINGS ON SECOND RECALL. ALSO NUMBER SHIFTED FROM LOWER TO HIGHEST RATINGS ON SECOND RECALL

Intervals	Pleasant		Unpleasant	
	From Highest into Lower	From Lower into Highest	From Highest into Lower	From Lower into Highest
2 days.....	46	35	29	23
4 days.....	74	39	24	16
7 days.....	54	36	19	15
14 days.....	22	15	9	5
28 days.....	19	18	9	8
49 days.....	16	18	15	15
70 days.....	27	15	10	7
140 days.....	13	10	6	6

number of items that on second recall were changed from the highest pleasant rating to some lower pleasant rating as well as those from some lower pleasant rating that were given the highest pleasant rating in the second recall. Similar data are also shown for the experiences of greatest unpleasant rating on the first recall. The figures of Table 3 are, of course, based on those experiences that were listed on both recalls. Since a systematic shift from highest to lower categories of affective rating is shown in these data the added experiences in second recall, whose shift cannot be reckoned, must be inferred to have been given a similar shift in affective rating. Now since the shift is shown to be a systematic one we are provided with a basis for reconciling the apparently contradictory results of Figs. 2, 4, and 5 on the relative retention of experiences differing in degree of affective value. That is, when no experiences are eliminated as in Fig. 2 there seems to be a better retention of experiences of slight affective value. However the data of Table 3 indicate that this result is chiefly an artifact resulting

from a tendency for experiences of extreme value to shift into more moderate categories with passing time. With the demonstration of this systematic shift it follows that Figs. 4 and 5, in which there has been an elimination of the experiences added on the second recall, give a truer picture of the relation between retention and degrees of affective value. In other words, the results seem to indicate that experiences of high affective rating tend to be better retained. Thus, gathering the strings of the preceding pages together, we arrive at the following statement of the relation between retention and affective tone, at least as far as the retention of experiences from everyday life is covered by our investigation: *The retention of experiences from daily life is unrelated to the qualitative character of their affective coloring but is positively related to the intensity or degree of such affective coloring.*

One further consideration of our data deals with the frequency with which the subjects had thought about or reviewed the experiences since they occurred. This was, of course, a task upon which absolutely accurate data could not be obtained, since the subjects had not kept an accurate account of such review. However they did not seem to have much trouble in indicating roughly the relative frequency with which this review had taken place. The data in Table 4 give the mean frequency of such review per experience for each category of affective rating based on the records of approxi-

TABLE 4

MEAN NUMBER OF TIMES EACH EXPERIENCE IN THE SEVERAL CATEGORIES WAS REVIEWED

Affective Rating	Frequency of Review					
	1	2	3	−1	−2	−3
Intervals						
2 days.....	1.2	1.7	4.7	2.9	2.9	8.9
4 days.....	1.7	3.2	6.6	2.1	4.3	7.7
7 days.....	2.6	4.6	7.9	3.6	4.8	7.3
14 days.....	3.9	7.3	11.4	3.1	6.4	22.6
28 days.....	8.4	10.2	15.8	4.7	9.2	13.6
49 days.....	2.3	5.1	11.5	2.9	4.5	16.8
70 days.....	9.4	6.8	17.1	6.3	6.2	20.9
140 days.....	1.3	2.1	4.8	1.0	2.9	3.9

mately half the number of subjects at each interval. As rough as the data were, only half were selected at random to give an indication of the general trend of review. These estimations, it will be remembered, were requested on the occasion of the second recall, which accounts for the fact of a generally-reported higher frequency with increase in length of interval.

Rough as the data of Table 4 are they give no support to a theory of more frequent review of the pleasant as opposed to the unpleasant. Comparing the data for each pair of corresponding ratings shows that at half of the intervals the pleasant are reviewed more frequently and at the other half the unpleasant are given the more frequent rehearsal. There is, however, a consistent trend toward a greater frequency of review of experiences of high affective rating as opposed to those of low affective rating. These data, it may be pointed out, are directly in harmony with and perhaps offer an explanation for the relative retention values found in this investigation.

Discussion of the Results

Several further remarks may be made to indicate the implication of these specific findings for certain broader problems that have been involved in discussions of investigations of this type.

The results of the present experiment harmonize with other similar experiments in finding more pleasant than unpleasant experiences reported by the subjects. This fact was to be expected in this particular experiment since the Christmas holiday period was under investigation. However, this fact of a difference in absolute number of pleasant and unpleasant experiences may constitute a limitation upon this and similar investigations, that is, different results might be obtained if the number of unpleasant experiences recalled had been as great or greater than the number of pleasant.

It has been suggested by Jersild, in the paper above referred to, that the better retention of the pleasant might be expected due to the fact that the individual will tend to review them more frequently than the unpleasant. Such

theoretically expected direction of review is not supported by our data collected on the frequency of such rehearsal. These data are admittedly, but unavoidably, crude. Crude as they are, however, they tend to show that the frequency of review is not related to the qualitative tone but rather to the intensity value of the affective ratings.

As we see it, our results do not bear on the status of the law of effect, nor, do we believe, does any other study of the relative retention of pleasant and unpleasant experiences. The law of effect as given by Thorndike is a principle which refers solely to the question of whether a subject would repeat the response if put into a situation similar to that in which he previously had experienced either pleasantness or unpleasantness. The law of effect says simply that the subject will tend to avoid *performing* the act that formerly was followed by unpleasantness, it says nothing about his *remembering* his former experience and the unpleasantness associated with it. As a matter of fact, from ordinary observation, we would conclude that generally the reason a subject does not repeat his former unwise actions is because of the very fact that he does remember them and their consequences. One might say that in stating his law of effect Thorndike was interested in nothing but the externally observable behavior of an animal and did not intend his law to do more than to account for just that. In studies of the relative retention of pleasant experiences we are trying to delve behind this surface phenomenon and get some data which may throw some light on the question of why different responses do or do not occur.

Finally our results offer no sure support to a theory of an active forgetting process. There is of course the possibility that such a process has had the opportunity of producing its effect during the interval between the experience and its first recall, but this possibility is very difficult to subject to experimental test. It is not our purpose to express a categorical denial of an active principle of forgetting. Perhaps the work of the psychoanalytic school is sufficient evidence for the existence of some such principle. But we do suggest that

the principle is not a general one, does not apply to the forgetting of large masses of material by a group or even by a single individual. Rather the principle is limited in its applicability. It might satisfactorily account for a few specific instances of forgetting by an individual, but the mass methods employed in this study would not be adequate to discover its presence.

Summary

This investigation was based on the recall of pleasant and unpleasant experiences by 245 students who had just completed the Christmas vacation. Two recalls were taken, one immediately following the vacation period, the second by different groups after intervals of 2, 4, 7, 14, 28, 49, 70, and 140 days. At each recall the subjects gave to each experience one of three degrees of affective value, slightly, moderately, or extremely pleasant or unpleasant. These ratings were assigned the experience as of the time of its occurrence. At the time of the second recall the subjects also indicated in round numbers the frequency with which they had reviewed each experience since it occurred.

Our study has led us to an appreciation of the fact that this problem is considerably more complex than is ordinarily realized and that interpretation is correspondingly hazardous. However, taking into consideration all the information we have, we do find evidence for the following conclusions:

1. There is a tendency for a systematic shift in affective ratings toward the more moderate categories.

2. The degree of affective value is positively related to retention.

3. There is no such marked relation between retention and the qualitative value, its pleasant or unpleasant character, of the experience.

4. These results are interpreted as having no bearing on the law of effect and as offering no sure support to a theory of an active forgetting process.

(Manuscript received December 26, 1934)

AN EXPERIMENTAL ANALYSIS OF THE VARIATIONS IN EFFICIENCY FOLLOWING THE NOON MEAL

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In the very extensive literature on diurnal variations in performance [1] frequent allusion is found to the influence of food upon the form of the curve of output. There is, however, little actual research upon the problem. The failure to control the food factor or to determine its exact influence has rendered many diurnal studies of doubtful worth.

The present work is an attempt to analyze experimentally the variations in efficiency which follow the ingestion of different quantities of food. Efficiency we define in terms of the relationship of work output to energy expenditure, following the method of Lovekin (**14**).

Studies which have been made upon the influence of food upon subsequent efficiency include: (1) those which have measured the diurnal effect upon some physiological indicator of energy expenditure, and (2) those which have measured the effects upon subsequent work output. Grollman (**11**) recorded changes in pulse, blood pressure, cardiac output and oxygen consumption following the eating of large and small meals. His data show that a rise in pulse, cardiac output, systolic blood pressure and metabolism results from eating. When a light lunch is ingested the pulse and cardiac output return to the normal (fasting) rate in about four or five hours, but with a heavy meal they require a much longer time to return to the normal. The minute volume of the heart is affected by food intake according to Collett and Liljestrand

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[1] See Freeman, G. L., and Hovland, C. I. Diurnal variations in performance and related physiological processes. *Psychol. Bull.*, 1934, 31, 777–799.

(5). The maximum effect was noted within an hour after the taking of food, the return to the normal requiring three hours after a light lunch and much longer after a heavy meal. Weysse and Lutz (18), Janeway (12) and Faught (7) all report increases in blood pressure after the intake of food. Maximum effects usually occur within an hour, the return to the normal rate being very gradual. Increases in temperature following the intake of food have been reported by Pembrey and Nicol (16) and by Benedict and Slack (3), but in neither study was the composition of the meal carefully controlled. The taking of food raises insensible weight loss, according to Benedict and Root (2) and Benedict and Joslin (1), but no mention of the kind or amount of food taken was made.

Excellent reviews of the effects of definite food elements upon metabolism will be found in Boothby and Sandiford (4) and in Lusk (15). In general, the effect of protein is to cause a rapid increase in metabolism, followed by a gradual decline. The effects of carbohydrate become progressively more marked over a long period. Fats seem to cause increases in metabolism which are maintained for a considerable time. Studies of fasting, which observe the results of omitting food over a prolonged period, give us no information concerning the immediate physiological changes involved.

Output changes associated with food intake are little understood. By allowing his subjects to alternate between eating breakfast and omitting it, Roemer (17) showed that fewer arithmetic problems were done when breakfast was not taken. Kraepelin (13) reports that the curve of efficiency following the meal has an initial drop, and then a continuous rise from three to four hours long. Finzi (8), however, says that there is a general and prolonged reduction in the speed of all functions following the taking of food. Dodge (6) found no consistent effect of food intake upon tapping rate, but the latency of word reactions was slightly lengthened. Glaze (9) (10) reported that sensitivity to odors is markedly increased following the omission of the noon meal.

It is difficult to interpret the precise effects of food intake upon performance, when either energy expenditure or work output alone is studied. For instance, the organism may

often compensate for the food loss by increasing its energy expenditure. On the other hand, output may fall while energy expenditure shows no reduction. Solution of the problem would seem to require the plotting of concomitant output and input changes.

Apparatus and Procedure

The apparatus was designed and the procedure planned in such a manner as to enable us to measure variations in the two factors which determine the efficiency of performance: (1) 'Input,' or the amount of energy which is exerted by an individual in accomplishing the tasks assigned, and (2) 'output,' or the amount of work which the individual is able to do within the experimental period.

Oxygen consumption and calorimetry appear to be the most suitable indices of the amount of 'input' or energy expended by the subject during work, but the difficulties arising from the use of a gas mask or calorimeter chamber have hampered the taking of measurements over long periods of time. A simpler procedure is offered by the measurement of weight loss due to insensible perspiration, a method which has been found by Benedict and Root (2) to correlate highly with the more conventional metabolic indices.

In this experiment insensible weight loss was measured by means of a one hundred kilogram balance with an accuracy of one part in a million. This extreme sensitivity made possible very accurate determinations of weight loss within a short period of time. The subject's cot was mounted upon one side of the balance. On the other side was mounted the pan which carried the weights. The scales were brought into equilibrium by placing enough weights upon the side opposite the subject to exactly counterbalance him. This absolute weight, expressed in grams, was recorded. At the exact moment when equilibrium was reached a stop watch was started, and the experimenter placed two additional grams upon the subject's side of the balance. The time, expressed in seconds, required for the subject to lose these additional grams was also recorded. Three such determinations were made each hour with the subject in a relaxed condition, and also during the performance of muscular and mental work. The energy expenditure of rest was always measured after the subject had relaxed on the weighing cot for a period of fifteen minutes.[2] Between readings the subjects rested on a cot, and hence exercise consisted solely of the walking from the outer cot to the one mounted upon the scale. Fifteen minutes, therefore, easily sufficed to establish a steady rate of loss.

To obtain an index of muscular work of the subject the number of finger oscillations made during two minutes were recorded. A finger ergograph was mounted directly on the cot so that the subject did not have to change his position in order to perform the task.

Continuous addition for a two minute period served as an index of performance at a higher level of neural systematization. Problems used were pasted upon a revolving wheel with an aperture directly in line with the subject's vision. This aperture allowed only one problem to be seen at a time. The subject gave the sum and the

[2] Benedict, F. G., and Wardlaw, H. S. H. (*Arch. Int. Med.*, 1932, 49, 1024) report that "the rate of insensible perspiration becomes constant, for all practical purposes, within thirty minutes."

wheel was then moved up to the next problem. The number of problems attempted, the number correctly solved and the number of errors made were recorded.

Ten subjects of normal height, weight, physique and health served. Their age range was from eighteen to thirty-four years. They were practiced upon the tapping and arithmetic tests for an entire day prior to obtaining the records used in this investigation. Two non-consecutive days were used for each type of meal, counterbalanced practice orders being employed.

The subjects were brought to a basal state before the commencement of the experiment. They were given preliminary tests during the morning hours to prevent an artificial rise in work output (initial spurt) for the period being investigated.

The standard meal consisted of a ham sandwich weighing 350 grams and a glass of milk weighing 220 grams. The large meal was made up by tripling the above rations. The divided meal was made by quartering the standard meal and administering the portions at hourly intervals throughout the afternoon.

Readings of weight loss were taken hourly after the ingestion of food, as follows: (1) during relaxation, (2) during tapping, and (3) during addition.

Results

The results are given below in a series of tables. Table I shows the number of grams lost per hour during relaxation following ingestion of various types of meals. Group averages are given for each of the conditions studied.

1. *Input of Relaxation*

TABLE I

Number of Grams Lost during Relaxation at Various Hours Following Food Ingestion

	Food	Hours after Food				
		1	2	3	4	5
Standard meal	35.91	40.57	41.06	39.05	38.03	36.89
Triple rations	36.74	40.04	44.87	46.95	44.28	41.26
Divided meal	36.27	39.77	42.15	43.82	44.16	43.57

2. *Input of Effort during Tapping*

Here we are interested in the amount of effort expended by the individual in achieving a given muscular task at the various hours following the noon meal. We have determined this expenditure of effort by dividing the weight loss during tapping by the weight loss during relaxation for the same hour. If no additional expenditure is required to do the finger oscillations over that required merely to relax, the

ratio will be 1.00 (100 in percentage form). The higher the ratio the greater the energy cost, since a greater amount of energy was expended to do the work than that required for the basal activity of rest. Table II presents these ratios at the various hours for the different meals.

TABLE II

RATIO OF ENERGY EXPENDITURE DURING TAPPING TO THAT DURING RELAXATION

	Food	Hours after Food				
		1	2	3	4	5
Standard meal	107.33	116.22	107.77	123.33	130.00	113.89
Triple meal	105.80	120.60	140.20	128.30	137.40	112.40
Divided meal	124.00	125.75	134.37	108.75	117.87	109.00

3. *Input of Effort during Addition*

In a similar manner we have compiled the number of seconds required to lose one gram weight during the arithmetical work, and from them the ratios of these losses to those obtaining during relaxation. These results are given in Table III.

TABLE III

RATIO OF ENERGY EXPENDITURE DURING ADDITION TO THAT DURING RELAXATION

	Food	Hours after Food				
		1	2	3	4	5
Standard meal	106.80	127.67	108.81	123.99	109.42	105.03
Triple meal	132.21	107.67	117.90	141.92	131.35	118.09
Divided meal	139.01	123.26	148.05	107.27	125.03	104.61

4. *Muscular and Mental Output Records*

The number of taps made at a given hour was reduced to percentage form by finding the ratio (in percent) which that hour's output bears to the maximum for the day. These ratios are shown in Table IV. Similar ratios for arithmetical output are given in Table V.

TABLE IV

RATIOS (IN PERCENT) OF TAPPING OUTPUT AT EACH HOUR TO DAY'S MAXIMUM

	Food	Hours after Food				
		1	2	3	4	5
Standard meal	92.1	95.3	100.0	94.3	96.2	97.9
Triple meal	95.9	100.0	96.5	97.9	96.5	95.2
Divided meal	89.2	93.5	90.1	93.4	98.4	100.0

TABLE V

RATIOS (IN PERCENT) OF ARITHMETIC OUTPUT TO MAXIMUM FOR DAY

	Food	Hours after Food				
		1	2	3	4	5
Standard meal	94.2	87.2	100.0	95.1	89.4	96.1
Triple meal	98.5	91.2	90.9	87.0	90.5	82.9
Divided meal	98.0	88.5	98.9	87.0	93.9	93.1

5. *Course of Efficiency*

Since efficiency is determined by output and input scores, a method of relating these data mathematically was utilized. Work output, expressed in terms of the ratio of the given output to the maximum for the day, was divided by the input of effort, the ratio of the weight loss during exertion to that during the resting state. This index number, found by the formula: Efficiency = Output/Input is the conventional way of stating efficiency in quantitative terms. It was employed independently by Lovekin (**14**) in a recent study of changes in efficiency in the industrial situation. Table VI gives the

TABLE VI

MUSCULAR EFFICIENCY RATIOS (OUTPUT DIVIDED BY INPUT) FOR VARIOUS HOURS AND DIFFERENT MEALS

	Food	Hours after Food				
		1	2	3	4	5
Standard meal	85.8	82.0	92.8	76.5	74.0	86.0
P.E.	3.4	2.4	3.2	2.2	3.1	2.4
Triple meal	90.6	82.9	68.8	76.3	70.2	84.7
P.E.	1.9	2.1	2.1	2.3	3.1	2.8
Divided meal	71.9	74.4	67.1	85.9	83.4	91.7
P.E.	3.1	3.1	3.4	2.4	3.6	5.0

ratios of efficiency for muscular work and Table VII those for mental work.

TABLE VII

MENTAL EFFICIENCY RATIOS (OUTPUT DIVIDED BY INPUT) FOR VARIOUS HOURS AND DIFFERENT MEALS

	Food	Hours after Food				
		1	2	3	4	5
Standard meal	88.2	68.3	91.9	76.7	81.7	91.5
P.E.	.82	1.4	1.4	1.3	1.8	2.1
Triple meal	74.5	84.7	77.1	61.3	68.9	70.2
P.E.	.6	2.4	1.6	1.7	1.6	2.4
Divided meal	70.5	71.8	66.8	81.1	75.1	89.0
P.E.	2.1	1.4	1.5	3.1	1.9	3.8

It will be noted that measures of variability are given only for the efficiency tables. There are two reasons for this. First, since efficiency is our main concern the other tables have only contingent and relative worth. Secondly, since these tables actually composite all of the data given in the preceding tables we may assume that their statistical reliability implies the reliability of the previous data.

AMPLIFICATION OF RESULTS AND DISCUSSION

Comparison of the changes in metabolism following the various types of meal, as shown in Table I, indicates a definite tendency for the heavy meal to require a longer period of increased metabolic processes than the standard or divided meal. This is what we should normally expect, and the work of Grollman (**11**) has shown that oxygen consumption follows a similar course to that reported here. The standard meal is followed by a slight initial increase in weight loss. Maximum loss occurs at two, and progressively decreases to the end of the day. When the meal was tripled the maximum occurs an hour later. This is probably due to the less rapid absorption resulting from the excessive food intake. The decline from the maximum follows a course similar to that taken after the standard meal. The input of relaxation following the divided meal suggests a series of superimposed effects; that is, each portion produces an effect similar to that

of the standard meal. The normal decline is offset by each new portion.

From Table II we see that the input of effort during tapping after ingestion of the standard meal follows somewhat the same course as that after the ingestion of the triple rations; both tend to involve the greatest energy cost in the late afternoon. The effect of dividing the standard meal is to increase the energy cost for muscular work in the early afternoon. The average differences in the effects of the various types of food intake can be summarized in Table VIII:

TABLE VIII

AVERAGE RATIOS (IN PERCENT) OF WEIGHT LOSS DURING RELAXATION TO LOSS DURING FINGER OSCILLATIONS AFTER VARIOUS FOOD INTAKES

Standard meal	116.42
Triple rations	124.12
Divided meal	119.96

From this table it will be seen that the triple rations and the divided meal require subsequently greater expenditures of energy than does the standard meal. The reason in the first case is the more obvious; in the second case we have already seen that the high expenditure only continues while the different portions are being taken, and that when the last portion is ingested the course of energy expenditure takes the form of that following the standard meal.

The input of mental work following the standard meal has no consistent direction of change. The triple meal tends to cause an increase in energy expenditure, while the divided lunch is followed by a progressively less energy consumption. Table IX gives the differences in the average energy expenditure under the various food intakes. As was the case with the input of effort during muscular work the triple rations and

TABLE IX

AVERAGE RATIOS (IN PERCENT) OF WEIGHT LOSS DURING RELAXATION TO LOSS DURING ADDITION AFTER THE VARIOUS FOOD INTAKES

Standard meal	113.62
Triple meal	124.86
Divided meal	124.54

the divided lunch result in greater energy expenditure than does the standard meal.

The number of finger oscillations, shown in Table IV, made after the standard meal and after the triple meal show little variation, although maxima occur in the early afternoon for both. The level of output is considerably higher following the standard meal. Muscular work following the divided meal increases steadily from hour to hour, each new portion providing a fresh impetus. Table X gives the average

TABLE X

NUMBER OF FINGER OSCILLATIONS MADE ON THE AVERAGE UNDER THE DIFFERENT EXPERIMENTAL CONDITIONS OF FEEDING

Standard meal	482.72
Triple meal	437.61
Divided meal	474.74

number of finger oscillations made in the afternoon following each type of meal.

The curves of mental and muscular output differ somewhat in their maxima and minima. There is steady decrement in mental work following the triple meal, whereas an increase obtains following the standard meal. As can be seen in Table V, the changes produced in mental work by dividing the noon meal have no consistent direction.

TABLE XI

AVERAGE NUMBER OF ARITHMETIC PROBLEMS DONE UNDER THE VARIOUS FOOD INTAKES

Standard meal	27.31
Triple meal	21.31
Divided meal	23.41

Muscular efficiency following the standard meal shows a pronounced increase at two P.M., while that following the ingestion of the triple ration falls during the early afternoon but then shows a pronounced end spurt (see Table VI). When the meal is divided muscular efficiency increases progressively from hour to hour. The standard meal seems superior to both the triple and the divided meal with respect to the total efficiency of performance (Table XII).

TABLE XII

AVERAGE RATIOS (IN PERCENT) OF RELATIVE MUSCULAR OUTPUT TO RELATIVE MUSCULAR INPUT AFTER THE VARIOUS FOOD INTAKES

Standard meal	82.85
Triple meal	78.91
Divided meal	79.07

The same general situation holds for mental efficiency as indicated by Tables VII and XIII. The general efficiency is greatest following the standard meal. These results are in accord with popular opinion which attributes decreased efficiency to a heavy meal, and also opposes frequent 'snacks.'

TABLE XIII

AVERAGE RATIOS (IN PERCENT) OF RELATIVE MENTAL OUTPUT TO RELATIVE MENTAL INPUT DURING DIFFERENT MEALS

Standard meal	83.05
Triple meal	72.78
Divided meal	75.72

SUMMARY

A systematic study was made of the effect of quantity of food taken upon the subsequent efficiency of ten male subjects. The types of food taken were the following: (1) a standard meal, consisting of one ham sandwich and one glass of milk, (2) a triple meal, consisting of three times the standard meal, and (3) a divided meal, the ham sandwich and the glass of milk being quartered and given at hourly intervals.

Insensible weight loss was measured hourly from 12 noon to 5 P.M. to have a measure of energy cost, under the following conditions: (*a*) basal activity of rest, (*b*) muscular work, and (*c*) mental work. Indices of output were obtained by the use of measures of tapping and addition problems. Input of effort during work was determined by the ratio of insensible loss during relaxation to the loss during the work. Efficiency was computed by the ratio of input to output.

Results suggest the following generalizations:

1. The triple meal is followed by much more pronounced metabolic effects than are the standard and divided meals.

2. Input of effort during muscular work is greatest following the heavy meal; is least following the standard.

3. Input for mental work is likewise greatest under condition (2) and least under (1).

4. Greatest output results following meal (1); the least following (2).

5. When measures of both output and input are combined into a single measure of efficiency, condition (1) shows the best subsequent effect, that is, under the standard meal condition, the least amount of effort is expended to do the greatest amount of work. Conditions (2) and (3) are both considerably less efficient for both muscular and mental work.

(Manuscript received January 7, 1935)

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THE COURSE OF ACQUISITION AND RETENTION OF CONDITIONED EYELID RESPONSES IN MAN

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Although the conditioned reflex was introduced into psychology chiefly as a method of experimentation with animals (**24**), and as a substitute for introspection (**21**), it shortly assumed an important systematic position in relation to habit formation. In some cases the conditioned reflex was accepted as the unit of habit (**22**); in other cases the conditioning principle became a substitute for association (**18**). Most of the textbooks of the last decade have introduced the concept of conditioning, some accepting it as a fundamental principle, others denying its general applicability to the familiar situations in which learning occurs. In spite of the systematic importance attached to the conditioned response by various writers, the detailed experimental analysis of conditioning as a learning process is relatively recent. Even Liddell, an active experimenter in the field, has recently denied any interest on the part of investigators in such problems as the rate of acquisition of conditioned responses (**11**, 292f.). On the other hand, several experiments have attempted to chart the course of performance in order that the relationships between conditioning and other examples of acquired responses may be interpreted in the light of functionally established similarities. These have been well summarized by Hull (**8**).

The primary object of this investigation was to determine the stability of conditioned responses in man over periods of time. The similarity or dissimilarity between conditioning and familiar forms of learning hinges partly on the answer to the problem of retention. It is known that extinction is usually temporary, but evidence is meager regarding the

permanence of the recovery which follows. Inasmuch as knowledge of original performance is essential to an understanding of retention, we have also studied certain aspects of the course of acquisition and extinction. The data to be reported, added to the evidence already in the literature, should serve to correct the erroneous belief that the results of conditioning are temporary and evanescent.

The investigation closely parallels a previous study of conditioning in dogs (7). Similar stimuli were used, and the reactions of corresponding bodily members were recorded. The experiments provide another comparative study, many of which are needed if we are to generalize safely from animal to human reactions.

Observations regarding individual differences in sensitivity and in the ease of formation of conditioned responses, not especially relevant to the present discussion, have been treated in a separate paper (3).

Procedure

The photographic recording of eyelid reactions by the Dodge procedure has been described elsewhere (5). The unconditioned stimulus, regularly eliciting an eyelid movement, consisted of a controlled air-puff striking the margin of the right eye.[1] Lid reactions were recorded from the left eye. All subjects showed reflex lid movements to the air-puff consistently; for two thirds of the subjects the lid closure of the recorded eye was approximately complete. The illumination change which served as the conditioned stimulus occurred on a circular field of frosted glass, 6 cm in diameter, at a distance of 50 cm from the eyes, thus subtending a visual angle of 7°. A 1.5 cm black cross was attached to the center of the glass as a fixation object. The field was viewed binocularly. The pre-stimulus brightness was 0.03 apparent foot-candles, and the brightness increased suddenly to 5.0 apparent foot-candles. This increase in brightness, controlled by a rapid silent shutter, constituted the conditioned stimulus. During conditioning trials, the light flashed on 400 ms before the air-puff occurred, and remained on until after reaction to the air-puff had subsided.

In all, 63 students of Stanford University acted as subjects. Each subject served for one experimental period on each of two consecutive days. Those who served in the retention experiment returned for a third period after the retention interval. This paper is concerned with the responses of the 51 subjects (34 men, 17 women) who served for three periods.[2] The following times elapsed between original

[1] The writers wish to acknowledge the technical assistance of Dr. Albert Walton in the construction and assembling of the apparatus, and throughout the course of the investigation. The state Emergency Relief Administration provided clerical help.

[2] Of the 12 subjects who did not return for a third day, 10 showed so little conditioning that they were not asked to return for a retention test, 1 left school, and for one the records of the third day were ruined. Individual differences in the responses of the first two days of the 63 subjects are treated in another paper (3).

conditioning and the test of retention, each subject serving at one interval: 1 day, 1 week, 4 weeks, 8 weeks, 20 weeks. The procedure used in matching the groups at the different intervals will be indicated later.

A single experimental session consisted of 50 joint presentations of the light and air-puff (reinforcements) at intervals of 20 to 40 seconds. Each trial was preceded by the verbal signal 'Ready.' The subject was instructed at this signal to fixate the cross on the circular area where the brightness change occurred. While a ready signal undoubtedly modifies the results of a conditioning experiment, it has the advantage of procuring greater uniformity in the organism antecedent to stimulation than is secured when no instructions are used. In addition to the reinforcement trials, each daily session began with five trials in which the unreinforced light was presented, and ended with ten such trials. These may be considered brief extinguishing series. Five control records of the reflexes to the air-puff alone were equally spaced among the reinforcement trials. One-minute rest periods intervened between the successive sets of 10 reinforcements, and between the final reinforcement and the extinction trials at the end of the session. The three days for each subject were alike, with one exception. For half the subjects the extinction trials were omitted at the end of the first day. Those for whom the extinction trials were omitted served as a control group for an analysis of the effect of extinction on the responses at the beginning of the following day.

The specimen record of Fig. 1 illustrates the responses which were recorded. The onset of the light occurred 400 ms before the air-puff. After a number of reinforcements, three responses were found on the record: (1) a reflex to light (R_L) of latency averaging 70 ms; (2) the conditioned response (CR) of longer latency, but occurring antecedent to the air-puff; and (3) the corneal reflex to the air-puff (R_P). It is possible to determine from each record throughout reinforcement whether or not a conditioned response was given, and the amplitude and latency of the response when it occurred. Amplitude values are reported in millimeters as read from the records, at a magnification of approximately four times motion at the eyeball; a response of 40 mm represented complete closure. There is some ambiguity at complete closure, due in part to the fact that an eyelid completely shut is still capable of motion, and in part to mechanical difficulties in recording by shadow. Responses recorded as 40 mm represent an undis-

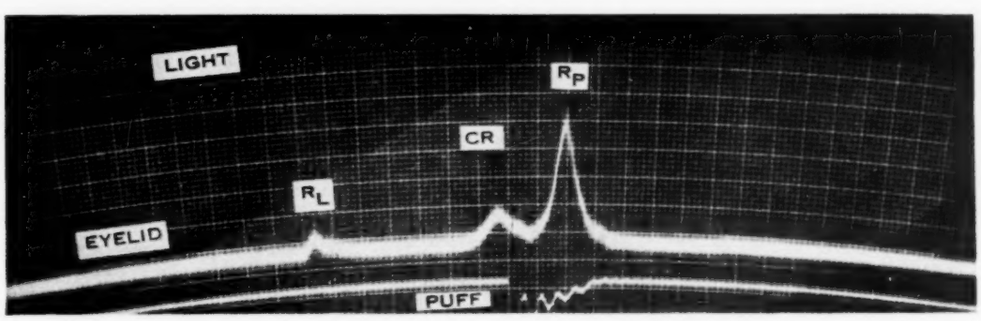

FIG. 1. Specimen record illustrating original reflexes and the acquired conditioned response. The record line, a shadow cast by an artificial paper eyelash (labelled 'eyelid'), indicates three responses: a reflex to the light (R_L), the conditioned response (CR), and the reflex to the air-puff (R_P). A rise in the line indicates lid closure. The onset of the light registers as a darkening at the top of the record, the air-puff as a break in the lower line. The curved abscissae are spaced at 1 mm on the original record. Vertical time lines occur every 10 ms, with emphasized lines at 50 ms. The interval between the light and air-puff is 400 ms. The whole record represents about two seconds of time.

tributed maximum; all 40 mm responses are by no means equivalent. Absence of response enters as zero amplitude into the calculations of mean amplitude in this report. That is, successive conditioned responses measuring 0, 0, 3 mm would yield a mean of 1 mm for the series of three responses. The responses of zero amplitude represent a population of sub-threshold or minimal responses which, like the 40 mm responses, resist further classification. In spite of these difficulties presented by minimal and maximal responses, progressive changes in mean amplitude are of significance for the analyses to be presented. Latency readings are obviously impossible for responses of zero amplitude, so that only the number of obtained conditioned responses can enter into calculations of mean latency. The range of possible latency values for the conditioned responses within reinforcement trials is constricted at the lower end by the occurrence of the reflex to light at short latencies (under 100 ms), and at the upper end by the reflex to the air-puff which followed the light by some 450 ms. Few conditioned responses crowd either of these extremes of latency, however, so that the latency readings are essentially free from distortion.

The Course of Acquisition of Conditioned Responses

The modifications of all responses have been followed throughout the successive trials in which reinforcement occurred. The mean values for the reflexes and conditioned responses of Day 1 and Day 2 are given in Table 1. The means are determined by averaging the mean values obtained from each 10-trial series from each of the 51 subjects. The amplitude of conditioned responses shows a gradual increase, especially through the first day, while the latency decreases. The average amplitude values of the second day are higher than those of Day 1, and the latency values lower, although the changes within the second day are not as regular as those within the first day. The reflexes both to the light and air-puff show a downward trend within each of the two days, with recovery over night. These changes are illustrative of the phenomena commonly designated negative adaptation or habituation, and are characteristic of repetitive performances. Very possibly the amplitude decreases in the conditioned responses in the later trials of Day 2 reflect a similar tendency towards decrease with repetition which counteracts the tendency for responses to increase with reinforcement. Similar tendencies were found within the responses of dogs by Hilgard and Marquis (7).

Examination of individual performance curves indicated that the mean amplitude values of Table 1 obscured certain differences. It was possible to throw the subjects into three groups, of which the mean performances are plotted in Fig. 2.

TABLE 1

CHARACTERISTICS OF REFLEXES AND CONDITIONED RESPONSES WITHIN REINFORCEMENT TRIALS ON TWO SUCCESSIVE DAYS OF CONDITIONING

Averages from the records of 51 subjects

Reinforcement trials	Reflexes to light (conditioned stimulus) Amp-mm	Reflexes to air-puff (unconditioned stimulus) Amp-mm	Conditioned responses	
			Amplitude in mm	Latency in ms
Day 1				
1–10	2.3	36.6	1.5	290
11–20	1.3	33.6	4.8	263
21–30	1.1	33.0	8.4	259
31–40	0.9	30.4	10.7	254
41–50	0.8	28.7	12.4	248
Day 2				
1–10	1.8	37.6	15.0	230
11–20	1.2	35.2	19.0	235
21–30	0.8	32.8	19.1	232
31–40	0.8	32.4	18.8	234
41–50	0.5	31.2	18.6	236

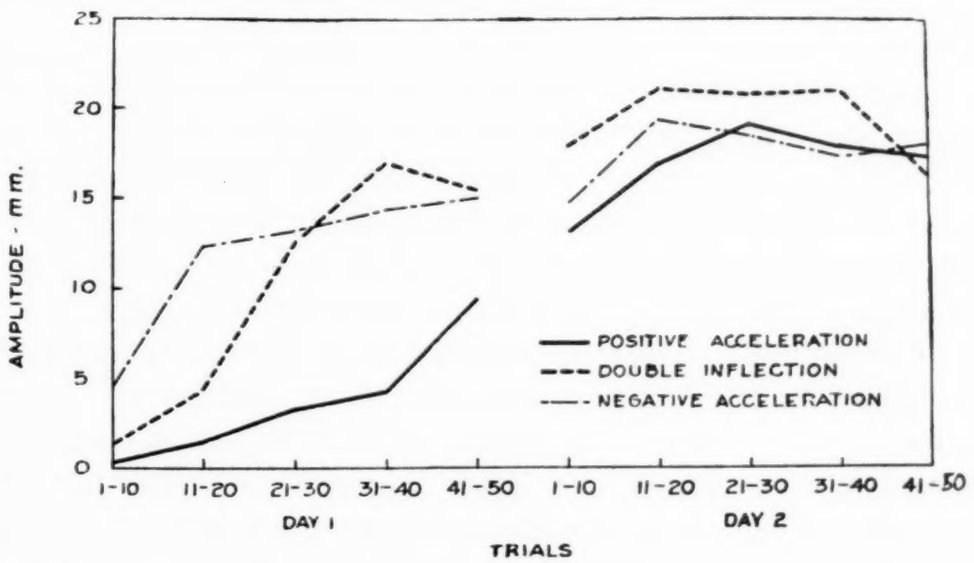

FIG. 2. The course of acquisition of conditioned responses within reinforcement trials on two successive days. The 51 subjects were arbitrarily divided into three groups on the basis of their performance curves. Group means were then determined by averaging the means of the subjects comprising each group. Only responses obtained within reinforcement trials are included, that is, responses occurring between the reflex to the light and the reflex to the air-puff as illustrated in the specimen record of Fig. 1. The group indicated as positively accelerated throughout Day 1 is composed of 23 individuals; next in order of size is the group whose average curve shows double inflection, consisting of 17 subjects; the group whose performance as plotted is primarily negatively accelerated consists of 11 subjects. There is evidence for initial positive acceleration even in the performance of this latter group, since the gain within the second bank of 10 trials is greater than the gain within the first 10 trials.

The most common curve for Day 1 was positively accelerated throughout, 23 of the 50 subjects (45%) fitting this picture. Next in frequency was the type of curve which showed initial positive acceleration, but reached a flexion point, became negatively accelerated, and in some cases dropped off after a maximum before the end of the day. The mean values for the 17 subjects (33%) of this group are also plotted in Fig. 2. Finally, 11 subjects (22%) gave values which are negatively accelerated after the first 10 reinforcements. The gain within the second ten reinforcements even for this group is greater than within the first ten, so that a period of initial positive acceleration is indicated, even though it is not evident in the plotted curve. The values for the second day are also presented in Fig. 2, and show that the tendencies for all groups are similar on that day. Possibly all of the curves belong to the same family of ogival or S-curves, differing simply in the rapidity with which the positive acceleration phase is completed.

The performances during the first 10 reinforcements of the second day continue to rise (in most cases) as though no extinction had intervened, although half the subjects had been given 10 extinction trials at the end of Day 1, and all had had 5 extinguishing trials at the beginning of Day 2. Recovery following extinction is discussed in more detail later.

The gradual course of acquisition of the conditioned response argues against the responses being voluntary. If the subjects were responding under deliberate self-imposed instructions to react to the light, it seems unlikely that the gradually rising curve would have been obtained. It is true that the responses are descriptively similar to voluntary responses, but criteria such as latency and form of response are not sufficient to serve as a basis of classification. Functional antecedents (previous responses, instructions, and so forth), must also be considered (**14**). Cason has recently discussed the significance of verbal factors in conditioning (**4**). Such factors play some part, as reports from our subjects show, but they probably do not account for the whole process. In some cases it was evident that the subjects were not aware of

the new response which they were giving to the light; in other cases subjects were disturbed by the fact that they were winking before the air-puff in spite of efforts to keep the eyes open and to maintain fixation until the air-puff occurred. Our instructions could not control these differences on the part of inexperienced subjects. Most of the subjects reported considerable detachment from the situation, *e.g.*, daydreaming of other things throughout the experiment.

Extinction and Overnight Recovery

Even after the conditioned responses had been much reinforced, as indicated in the previous section, a few presentations of the light without the air-puff resulted in marked extinction. The values for successive trials within the 10-trial extinguishing series at the end of Day 2 are given in Table 2.

TABLE 2

Characteristics of Reflexes and Conditioned Responses to Light Within Extinguishing Trials at End of the Second Day of Conditioning

Averages from the records of 51 subjects

Extinction trial	Reflexes to light Amp-mm	Conditioned responses	
		Amplitude in mm	Latency in ms
1	1.0	22.4	238
2	0.7	12.8	266
3	0.4	7.8	260
4	0.4	4.8	259
5	0.2	4.8	285
6	0.3	4.3	265
7	0.2	2.9	263
8	0.2	6.4	264
9	0.5	4.9	277
10	0.6	2.7	239

The short series is sufficient to reduce the amplitude below that of trials 11–20 of the first day of conditioning; in other words, so far as response manifestations are concerned, 10 extinguishing trials have undone temporarily the work of some 90 reinforcements. The regular decline in amplitude which results from combining the data from a number of

subjects is somewhat misleading. Of the 51 subjects, one gave no conditioned responses during the extinction trials, although he had given 7 conditioned responses within the last 10 reinforcements; 3 subjects gave no responses on the first extinction trial, but responded on later trials; for 7 subjects the first trial of the extinction series was the only one to yield a conditioned response; the remaining 40 subjects gave from 2 to 10 conditioned responses, usually of decreasing amplitude, although occasionally a response of large amplitude emerged after several trials without a response. The gradual decrease of response during extinction, along with increasing latency, is typical, although by no means universal.

Before entering upon the study of retention over longer periods, it was deemed advisable to analyze the overnight effects between Day 1 and Day 2, in order to determine the after-effects of extinction. To this end, subjects were divided into two groups, one of which received extinction trials at the end of the first day, the other having been dismissed without extinction at the end of the 50 reinforcements. All subjects were treated alike on the second day. The performances at the beginning of the second day were studied for the effect, if any, of the different treatments at the end of Day 1. When the two groups were compared, it was found that the random distribution of subjects into one group or the other had not resulted in comparable groups, the experimental group having by chance turned out to have a higher average amplitude of conditioned responses at the end of Day 1. It became necessary therefore to select from among the total number of subjects two groups more nearly equated. For this purpose, subjects were arranged in the order of mean amplitude of conditioned responses throughout the reinforcements of Day 1. To match each subject of the experimental group that subject of the control group was chosen whose average amplitude and course of performance was most like the experimental subject. It was possible to secure fairly good matching in 18 pairs of subjects. Data from these pairs are presented in Table 3. From the mean of 7.8 mm in the last 10 reinforcement trials, the responses of the experi-

TABLE 3

EFFECT OF EXTINCTION AT END OF DAY 1 ON CONDITIONED RESPONSES WITHIN THE EARLY TRIALS OF DAY 2

	Amplitude of Conditioned Responses in mm	
	Experimental group (18 subjects) Mean and σ_m	Control group (18 subjects) Mean and σ_m
Day 1		
Final 10 reinforcements	7.8±2.1	7.5±2.0
Extinguishing trials at end of day (experimental group only)—Trials 1–5	3.0±0.8	
Trials 6–10	2.0±0.9	
Day 2		
Initial extinguishing trials	3.2±1.1	3.4±1.9
First 10 reinforcements	10.7±2.3	10.7±2.4

mental subjects dropped to a mean of 3.0 mm in five extinguishing trials, and to 2.0 mm in five additional trials. There is recovery overnight, so that five extinguishing trials at the beginning of Day 2 yield responses of a mean amplitude of 3.2 mm, comparable to the value obtained in the trials immediately after conditioning. The control subjects, lacking extinction at the end of Day 1, begin Day 2 at approximately the same amplitude as the experimental subjects, indicating that the permanent effects of extinction, if any, are slight. The means for the first 10 reinforcements of the second day are alike for both groups of subjects.

THE RETENTION OF CONDITIONED RESPONSES

By allowing different periods of time to elapse before a third day of conditioning, and by comparing the reconditioning with the earlier conditioning, the effect of lapse of time upon the retention of the conditioned response could be ascertained, provided the retention groups were comparable with respect to original conditioning. The number of subjects conditioned and retested at each interval was as follows: 1 day, 11; 1 week, 10; 4 weeks, 8; 8 weeks, 10; 20 weeks, 12. The order in which the intervals were arranged was chiefly a matter of convenience, although care was exercised that the order was not one of simple progression from shorter to

longer, or the reverse. That the whole experiment might be performed in a minimum of time, the twenty weeks subjects were conditioned first, and retested after conditioning and retesting most of the other subjects. Apparatus and instructions remained as nearly uniform throughout the experiment as they could be made; the more or less random order of the conditioning and retention tests prevented the entrance of a systematic error.

Of the many possible measures of retention, we have chosen two as most straightforward. The first of these is a comparison of the conditioned responses in five trials to the unreinforced conditioned stimulus after the retention interval with those which were given in five similar unreinforced trials at the end of the second day of original conditioning. The results of this comparison are given in Table 4. Since the

TABLE 4

RETENTION OF CONDITIONED RESPONSES AS MEASURED BY UNREINFORCED TEST TRIALS

Interval Between Day 2 and Day 3	Conditioned Responses in 5 Initial Non-reinforced Trials of Day 3 Compared with First 5 of the Non-reinforced Trials at the End of Day 2							
	All Subjects				Groups with Equated Day 2 Means			
	Number of Subjects	Day 2 —mm	Day 3 —mm	Ratio $\frac{\text{Day 3}}{\text{Day 2}}$	Number of Subjects	Day 2 —mm	Day 3 —mm	Ratio $\frac{\text{Day 3}}{\text{Day 2}}$
1 day.....	11	14.0	9.5	0.68	9	11.6	7.0	0.60
1 week.....	10	11.7	7.8	0.67	10	11.7	7.8	0.67
4 weeks.....	8	8.4	6.1	0.73	5	11.9	8.5	0.71
8 weeks.....	10	12.3	9.1	0.74	9	11.8	8.3	0.70
20 weeks.....	12	7.8	6.3	0.81	5	11.5	5.7	0.50

different retention groups yielded rather different values at the end of original conditioning, results are presented also in terms of equated groups. The groups were so small that subjects could not be paired against each other without reducing the number in each group so greatly that chance errors might negate the advantages of equating. The mean amplitude values were therefore adjusted by eliminating subjects with large mean values from the groups whose means were

high, and subjects of small mean values from groups whose means were low. The result is groups of equal mean values, but containing different numbers of subjects. It is evident that lapse of time has an inappreciable effect on the retention of conditioned responses by this criterion. Such slight differences as occur are statistically unreliable, because of the large variabilities of the values.

The second measure of retention is a comparison of reconditioning with original conditioning. The amplitude of conditioned responses within the first ten reinforcements after the retention interval is compared with the final ten reinforcements previous to the lapse of time. This is a more reliable measure than the one in terms of retest before reconditioning, chiefly because of the larger population of responses involved. Not only are there 10 records per subject rather than 5 determining the mean value, but of these 10, some 90% contain conditioned responses, whereas within extinguishing trials responses are much fewer. Neither measure is wholly satisfactory. A retest in terms of extinguishing trials is a compromise measure between retention and extinction. A reconditioning series is a compromise between retention and new conditioning. The reliabilities of the two measures may be expressed statistically in terms of the correlation between the values of Day 3 and the values of Day 2 with which they are compared in the retention tests. The differences in retention intervals have been ignored in these calculations, so that the values represent retest reliability over periods of time from 1 day to 20 weeks. The retest scores on which the values of Table 4 are based (comparisons of extinguishing trials) show a coefficient of correlation of $r = + .67 \pm .05$ between the end of Day 2 and the beginning of Day 3. The reconditioning scores, from which the values of Table 5 are derived, yield an $r = + .85 \pm .03$. Both correlations are based on 51 pairs of values, from as many subjects.

The results of the reconditioning test are presented in Table 5, again in terms of all subjects, and of groups of subjects equated for mean amplitude of responses at the end of original conditioning. Results agree with those of Table 4

TABLE 5

RETENTION OF CONDITIONED RESPONSES AS MEASURED BY RECONDITIONING

Interval Between Day 2 and Day 3	Conditioned Responses Within First 10 Reinforcements of Day 3 Compared with the Final 10 Reinforcements of Day 2							
	All Subjects				Groups with Equated Day 2 Means			
	Number of Subjects	Day 2 —mm	Day 3 —mm	Ratio $\frac{\text{Day 3}}{\text{Day 2}}$	Number of Subjects	Day 2 —mm	Day 3 —mm	Ratio $\frac{\text{Day 3}}{\text{Day 2}}$
1 day.....	11	25.0	21.6	0.86	7	18.6	18.2	0.98
1 week.....	10	18.7	21.2	1.13	10	18.7	21.2	1.13
4 weeks.....	8	14.6	17.8	1.22	6	18.7	21.6	1.15
8 weeks.....	10	21.0	26.6	1.27	7	18.6	23.1	1.24
20 weeks.....	12	13.5	14.2	1.05	8	18.6	17.7	0.95

in showing a tendency for there to be greater, rather than less, amplitude of conditioned responses, up to 8 weeks, with little reduction by 20 weeks. The differences between the intervals are not statistically significant. The essential hypothesis being tested—that conditioned response modifications are relatively stable over periods of time—is amply demonstrated. Such responses have been shown to persist for periods of time up to 20 weeks, the longest interval tested, whether the comparison is made in terms of reactions during test trials with the non-reinforced conditioned stimulus, or in terms of reconditioning after the interval.

Although the form of the curve of retention cannot be determined reliably from our data, the tendency for there to be a rise instead of a fall with lapse of time (Fig. 3) led to a search for some explanation within the data. It was thought possible that recovery from negative adaptation may have reactivated the reflexes, and that with this increase in sensitivity went increase in conditioning. The values presented in Table 6 show this possibility to be confirmed, especially with respect to sensitivity to light as measured by the reflex response, somewhat with regard to sensitivity to the air-puff. The ratio of third day reflexes to light to those of the second day is lowest 1 day after the original conditioning, and increases gradually until the final 20 weeks retest. Values for the equated groups, not presented, have been calculated and

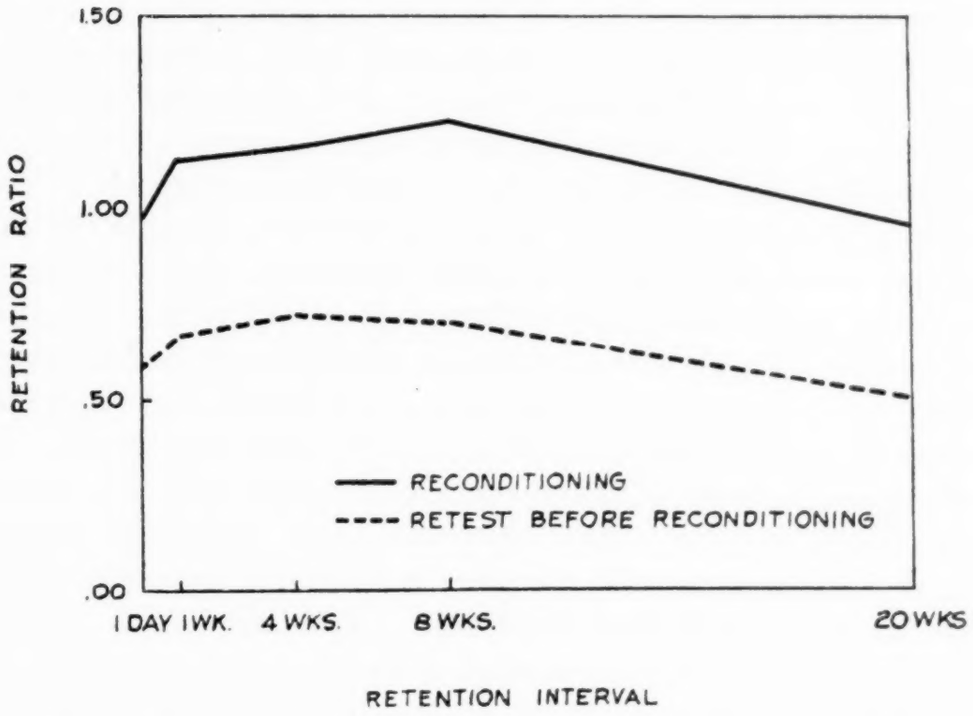

FIG. 3. Retention of conditioned responses over intervals of 1 day to 20 weeks. The mean values of the equated groups, Tables 4 and 5, are plotted. The retention ratio is obtained by dividing the performance on the third day (after the interval) by the performance on the second day (original conditioning). The ratio based on retest trials before reinforcement compares the five extinguishing trials after the interval with five similar trials which followed immediately the end of the original conditioning. The ratio based on reconditioning compares the first 10 reinforcements after the lapse of time with the last 10 of the original conditioning. Both retention ratios are to be interpreted relative to the 1-day values. Variability is great, and the form of the retention curves is not to be relied upon except as a demonstration that there is retention over the longest period studied.

TABLE 6

CHANGES IN REFLEX SENSITIVITY BETWEEN DAY 2 AND DAY 3

Interval Between Day 2 and Day 3	Amplitude of Reflexes to Light (R_L) Within 50 Reinforcement Trials			Amplitude of Reflexes to Air-puff (R_P) Within Control Trials		
	Day 2 —mm	Day 3 —mm	Ratio $\frac{\text{Day 3}}{\text{Day 2}}$	Day 2 —mm	Day 3 —mm	Ratio $\frac{\text{Day 3}}{\text{Day 2}}$
1 day.....	1.85	1.24	0.67	36.7	36.3	0.99
1 week.....	1.12	0.92	0.82	36.3	33.3	0.92
4 weeks....	0.71	0.63	0.89	32.7	29.4	0.90
8 weeks....	1.11	1.48	1.33	34.4	36.3	1.06
20 weeks....	0.57	0.83	1.46	29.6	33.3	1.13

show similar tendencies. While the mean amplitude values of the reflexes to light are small, each is the average of hundreds of records (50 per subject), and the tendencies are significant. No attempt has been made to apply a correction to the retention ratios for the conditioned responses on the basis of these changes in reflex sensitivity, because of the logical and statistical difficulties involved. It is evident, however, from inspection of Tables 4, 5, and 6, that the low values for 1 day retention parallel decrement in reflex sensitivity to light; similarly, the values of 8 weeks and 20 weeks are to be interpreted in relation to high reflex sensitivity. A correction in terms of reflex sensitivity would raise the retention scores for the shorter intervals, and lower the values for the longer intervals, yielding a function showing initial rise (at least for 1 week retention as compared with 1 day) possibly with gradual decrement after 1 week.

That differences in reflex sensitivity do not account for the whole of the third day increase in conditioning over the second day is evident when the results from all subjects are pooled. Values of reflexes to the light, reflexes to the air-puff, and conditioned responses throughout the third day, are presented in Table 7 for comparison with corresponding values

TABLE 7

CHARACTERISTICS OF REFLEXES AND CONDITIONED RESPONSES WITHIN REINFORCEMENT TRIALS OF DAY 3, AFTER INTERVAL OF TIME FOLLOWING DAY 2
Averages from the records of 51 subjects

Reinforcement Trials	Reflexes to Light (Conditioned Stimulus) Amp-mm	Reflexes to Air-puff (Unconditioned Stimulus) Amp-mm	Conditioned Responses	
			Amplitude in mm	Latency in ms
Day 3				
1–10	2.0	37.6	20.5	226
11–20	0.9	35.0	22.4	228
21–30	0.9	33.4	22.6	237
31–40	0.6	33.2	22.6	232
41–50	0.7	30.4	21.6	234

for Day 2 which appear in Table 1. The results for Day 2 and Day 3 are charted together in Fig. 4. Only for the conditioned responses are there consistent differences between the

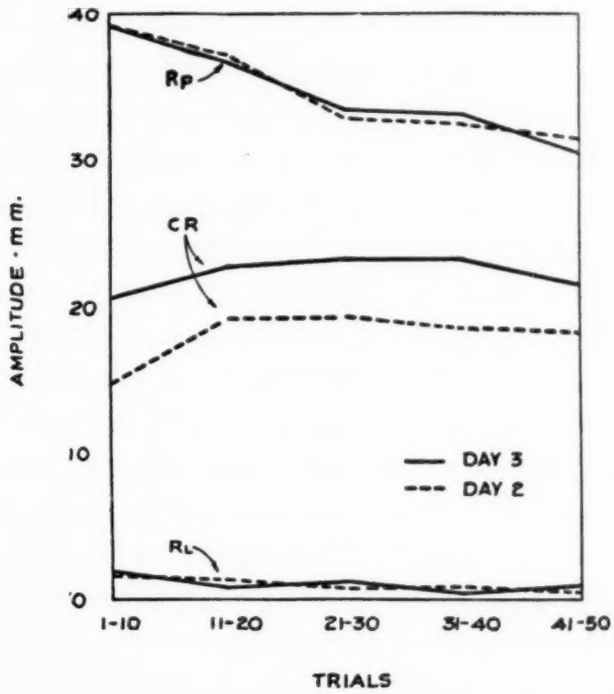

FIG. 4. Reflexes and conditioned responses of day 3 compared with those of day 2. The reflexes to light (R_L) are plotted from the same records which yielded the values for the conditioned responses (CR). The reflexes to the air-puff (R_P) are from control records interspersed among the reinforcements. All 51 subjects are pooled, so that the Day 3 values are separated from the Day 2 values by periods of from 1 day to 20 weeks. It is evident that Day 3 continues conditioning beyond the performances of Day 2; the reflexes to the light and air-puff are of similar amplitude on the two days.

two days. The conditioned responses of the third day begin, on the average, at higher values for the first 10 reinforcements than were yielded in the last 10 reinforcements of Day 2, and the values remain consistently above the Day 2 values. On both days there is a maximum increase within the early trials of the day with a decrement shown in the last trials. The third day continues the course of performance of the second day, whether an interval of one day or of 20 weeks elapses between them. Changes with time proved to be too small for us to chart their course with precision from our limited data. On the other hand, these data show sufficient internal consistency that such differences would have been detected had decrement with time been large.

Discussion

1. *Conditioning and Forgetting.*—The choice between contradictory assertions regarding the conditioning process can often be made upon the basis of facts as they become available. We find it stated that "Conditioned reflexes are often difficult to establish, requiring laborious repetition, and, once established, they soon fade out." (**2**, 186). Another writer says: "Nothing like the 'curve of forgetting' appears with the conditioned reflex" (**6**, 116). Both sets of implied facts—that conditioned responses soon fade, and that they are extremely resistant to forgetting—are used by some to argue that conditioned responses are not typical representatives of usual forms of learning. Probably both of the statements quoted above are misleading generalizations. While our data show that conditioned responses may persist at or above original values for a number of weeks, they do not prove that they are not subject to forgetting. In studying forgetting the factor of overlearning has to be taken into account, and the cues to recall are important. There is not only a great amount of overlearning in a situation such as that met in this investigation, but the cues for the reinstatement of the response are prominent. Our subjects returned to an apparatus which they recognized (an easy memory performance, even after 20 weeks), and the stimulating devices were present before any stimuli occurred. Instructions regarding fixation were repeated. It is not surprising, therefore, that the results of previous experience in the situation were evidenced in the first trials after the retention interval. The plausibility of our findings on these grounds does not negate their significance; exactly the same considerations apply to Pavlov's dogs which retain salivary conditioned responses when they are returned to his special laboratory. Guthrie (**6**, 117 ff.) has rightly pointed out that these laboratory cues do not become alienated from the appropriate conditioned responses during the retention interval, and hence forgetting due to facts covered by associative and retroactive inhibition does not occur. If the same subjects returned to the conditioning laboratory for other purposes, and were trained to give

antagonistic responses, it is probable that more 'forgetting' for the original conditioned responses would be shown. This is a matter for investigation rather than for debate.

A number of studies testify to the fact that conditioned responses can be retained for relatively long times, although technical difficulties have thus far prevented there being any satisfactory quantitative study defining the curve of retention.[3] Fish have demonstrated retention for as long as 11 months (**19**); frogs for one month (**10**); pigeons for several weeks (**1**)(**20**); chickens for 11 weeks (**25**); sheep for 6.5 months (**12**); dogs for 15 weeks (**7**). Children have been shown to retain conditioned responses for 31 days (**23**) and for 49 days (**9**). The single case which is cited of an idiot demonstrating conditioning after 2 years is scarcely to be relied upon (**16**). Rats have been found to lose all evidence of conditioning within two months (**17**).

2. *The Course of Acquisition.*—The double inflection or S-curve is again shown to be the typical form of the curve of acquisition of conditioned responses, although individual subjects differ widely in the relative prominence of the phases of positive and negative acceleration. Decrement occurs within single conditioning sessions before maximum conditioning is reached. That is, responses on successive days, showing decrement within each day, will reach successively higher maximum values. This fact bears both upon the familiar results of experiments on skill which show short practice periods to be favorable, and upon Pavlov's assertion that all conditioned responses tend to develop inhibition with long-continued reinforcement (**13**). Experiments are needed to determine the nature of the decrements which Pavlov groups together as illustrations of internal inhibition, of which experimental extinction is the most familiar example.

3. *Comparisons Between Man and Dog.*—The similarities between our experiments and those of Hilgard and Marquis (**7**) on dogs makes it worthwhile to compare the results. The paradigm was similar in the two cases: for both man and dog

[3] Razran's helpful summaries of conditioning (**15**) (**16**) have been the source of several of these references.

an illumination change was reacted to by a short-latency lid reflex followed by a longer latency conditioned response anticipating the lid reflex to an air-puff striking the cornea. The reflex to the light for the dog was a slight lid opening, for man a slight closure. The lid response to the air-puff was bilateral in man, more nearly unilateral in the dog; the conditioned responses of the dog were correspondingly unilateral, while for man they were bilateral.[4] The course of acquisition for the dog showed the double inflection characteristic of the human performance curves, but the responses developed more slowly in the dogs, and extinguished more slowly. The relative rates of conditioning and extinction are not strictly comparable in the two experiments, because the dogs were given more adaptation trials prior to conditioning, and had more extended conditioning before extinction; other considerations, however, argue against the differences being entirely attributable to those differences in procedure. With regard to overnight recovery and retention over longer intervals, the results for man and dog are as similar as the limited experimentation could reveal. Decrement within the day, after responses had reached a given magnitude, was found alike for both. Recovery was found to be proportionately greater following responses of small amplitude than following responses of large amplitude, in both cases.[5]

The similarities between the results on species as diverse as man and dog lend hope that the 'laws of conditioning' may prove to be ascertainable. Their discovery and statement in precise form seem to us to be essential preludes to the under-

[4] The reproduced record of Fig. 1 shows only the reaction of the non-puffed eye. For purposes of calibration, records were secured simultaneously from both eyes of several of our subjects. The lid reflex of the non-puffed eye shows more rapid decrement than that of the eye receiving the air-puff, although the latency of the responses of the two lids seems to remain alike.

[5] Chance responses might account for the apparent greater increase of small responses over large responses, because of the limited maximum amplitude values. They cannot account for the fact that following responses of large amplitude there is no longer overnight recovery, but loss. The facts seem to be related to the inflections of the performance curve, gains being rapid at first, finally reaching a place where there is loss, even with reinforcement. It is of interest that these inflections are found for inter-session increases as well as for intra-session increases.

standing of the conditioning process, and to the interpretation of conditioning in relation to other forms of modified performances.

Summary

1. Eyelid reactions are reported from 51 subjects conditioned on two successive days and reconditioned after intervals of 1 day, 1 week, 4 weeks, 8 weeks, and 20 weeks, each subject serving at one interval. An illumination increase which elicited reflexes of small amplitude preceded by 400 ms an air-puff to one cornea which evoked approximately complete lid closures. The conditioned response appeared as a lid reaction following the light by a latency greater than that of the reflex, but occurring before the onset of the air-puff. This made it possible to study the characteristics of the conditioned responses throughout the reinforcement trials.

2. The course of acquisition of the conditioned responses was studied on the basis of average amplitude of response within successive 10-trial series throughout conditioning. The acquisition curve is typically of S-form, positively accelerated, at first, becoming negatively accelerated, and dropping off after a maximum point is reached. Subjects differ greatly in the duration of the phase of positive acceleration. Latency tends to decrease as amplitude increases. The gradual development of the conditioned responses argues against their interpretation purely in terms of volitional or verbal processes.

3. Brief extinguishing series (10 trials with the non-reinforced light) result in marked decrement.

4. The effect of extinction at the end of the first day of conditioning is evidenced very slightly, if at all, in the responses at the beginning of the second day. This was demonstrated by the equality of initial performances on the second day of two paired groups of subjects, only one of which had undergone extinction at the end of Day 1. This agrees with Pavlov's findings that extinguished responses may recover with lapse of time.

5. Retention as tested by a comparison of initial non-reinforced trials of Day 3 with non-reinforced trials at the end

of Day 2, before the retention interval, shows no significant changes with time, although for equated groups there is a slight tendency for increased response over one day values up to eight weeks, and a slight decrement below one day values by 20 weeks. Comparison of the amplitude in the first 10 reinforcements after the retention interval with the final 10 reinforcements at the end of original conditioning, shows similar tendencies. When responses of all subjects are considered, the lowest retention value is found at one day, the highest at 8 weeks. For equated groups the rise is continuous to 8 weeks, but falls to the one day level by 20 weeks. While the form of the curve of retention cannot be described accurately from these data, the results indicate unequivocally that conditioned responses may be retained at approximately full amplitude values for periods of time up to 20 weeks, the longest interval tested.

6. Part of the rise in amplitude values after lapse of time may be attributed to increased reflex sensitivity, as measured by reflex responses to both the light and the air-puff. If corrections were made for reflex sensitivity, more forgetting would be evidenced at the longer intervals, although the one week values would still be above the one day values.

7. Comparisons between the course of conditioning, extinction, and retention of eyelid responses in man and dog reveal many functional similarities, in spite of differences in reflex responses and the necessarily unlike circumstances of experimentation upon such diverse forms.

(Manuscript received March 9, 1935)

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